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of the
American Association *of* Petroleum Geologists

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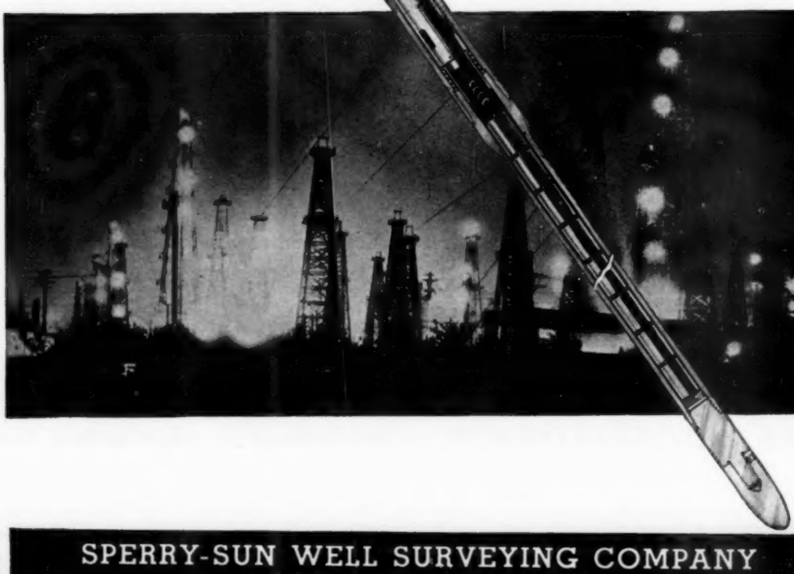

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NOVEMBER, 1939

CORRELATION OF SURFACE AND SUBSURFACE FORMATIONS IN TWO TYPICAL SECTIONS OF THE GULF COAST OF TEXAS[1]

ALEXANDER DEUSSEN[2] AND KENNETH DALE OWEN[3]
Houston, Texas

ABSTRACT

The writers offer two typical sections of the Texas Gulf Coast, one from Fayette County to Matagorda County and another from McMullen County to Nueces County, based on the electrical logs of wells drilled in the line of the sections.

Correlation from well to well is based on the electrical characters of the several formations, in addition to their foraminiferal content.

The several formations are traced through in the respective sections from the deep underground to the surface.

Attention is called to the presence of the marine shale Oligocene wedge in the subsurface not represented in the surface section.

Attention is likewise called to the inaccurate correlation of the so-called subsurface Frio with surface Frio formation.

Suggestion is made that the four stratigraphic units disclosed by the subsurface section, not present in the surface section, be properly named.

Early geologic exploration in the Gulf Coast of Texas was necessarily restricted to the examination of outcrops. The geologic column at that time established was based on these outcrops and the large fossils that they contained. And what was known of the depositional and geologic history of the Gulf Coast at that time was determined from this column so constructed.

When Kennedy in 1892 described the Tertiary and Quaternary formations of the Gulf Coast[4] he did not have the benefit of any subsurface information. There were in the state at that time very few water wells more than a few hundred feet in depth.

[1] Presented before the Association at New Orleans, March 18, 1938. Manuscript received, June 30, 1939.

[2] Consulting geologist, 1006 Shell Building. The writers wish to acknowledge the assistance of Lloyd J. Broussard, of Houston, Texas, associate of the junior writer, in the construction and preparation of the large cross sections.

[3] Consulting geologist, 824 Esperson Building.

[4] William Kennedy, "A Section from Terrell, Kaufman County, to Sabine Pass on the Gulf of Mexico," *Third Ann. Rept. Geol. Survey Texas* (1892), pp. 43-125.

In 1891 work was begun on the drilling of the well on Galveston Island, by the City of Galveston, in search of a supply of fresh underground water. This well reached a depth of 3,070 feet, and was referred to, and described as, the Galveston deep well. It was then considered that this depth of 3,070 feet represented the ultimate limit to which wells could be drilled.

Now, 50 years later, wells are being drilled to a depth of 15,000 feet, and wells between 11,000 and 12,000 feet are fairly common.

It is needless to say that there was no thought of oil in connection with the drilling of the Galveston well, as this was 9 years before the discovery of oil at Spindletop.

The drilling of this well resulted in the first important contribution to the knowledge of the underground geology of the Texas Gulf Coast, because it disclosed the presence of marine Miocene fossils in the subsurface section, there being no marine Miocene in the surface section.[5]

When oil was discovered in the Gulf Coast in 1901 (at Spindletop) it was almost as much a boon to the geologist as to the oil man, for it opened to him a wealth of data that otherwise he never could have obtained. The records of these early wells, however, while valuable, were at best poor sources of information. In most records, the only information afforded was the so-called driller's log, ordinarily compiled from memory, with little attention to an accurate description of the formations encountered. For many wells, no log was kept.

The only opportunity to examine the character of the actual beds encountered was afforded by the cuttings brought up with the drill mud, and at most wells these cuttings were not saved, but were promptly discarded. At a few wells, during blowouts, larger fragments of the underground beds might be expelled, and these gave some information on the character of the beds. The first samples of cap rock, commonly present on top of the salt domes, were obtained in this manner. Cores of the formations, now secured from almost every well, were then unknown.

These early oil wells disclosed for the first time the presence of those important underground structures now known as salt domes, until then not suspected.

The Galveston deep well in 1892 gave the first inkling of that important series of sediments missing in the surface section, which is now referred to as the marine Miocene, and the discovery of microscopic lower Oligocene fossils in a well at West Columbia in Brazoria

[5] G. D. Harris, "Preliminary Report on the Organic Remains Obtained from the Deep Well at Galveston, together with Conclusions Respecting the Age of the Various Formations Penetrated," *Fourth Ann. Rept. Geol. Survey Texas* (1893), p. 118.

County[6] in the year 1923 gave the first evidence of another series of sediments, likewise missing at the surface, which is now known as the marine Oligocene.[7] Both marine wedges represent deep-sea deposits, laid down in a sinking geosynclinal basin underlying part of the present Gulf Coast area.[8]

Since the time that the first geologic descriptions of the Texas Gulf Coast were attempted in the early 90's of the last century, the several authors have constructed graphic sections, attempting to show the composition and structure of some portion of the underground. The senior writer presented one of these sections in 1914[9] and another in 1924.[10]

The graphic sections constructed in these preceding years were necessarily crude, due to the limited information available. Rarely was the attempt made to show the nature and relations of the geologic formations, known at the surface, to a depth of more than 3,000 or

[6] Humble Oil and Refining Company's Lovejoy No. 1.

[7] While the presence of marine Oligocene in the subsurface was not proved until the discovery at West Columbia in 1923, its existence was postulated as early as 1918.

In a manuscript submitted by E. T. Dumble to the Bureau of Economic Geology at Austin, Texas, in 1918, but not published until 1920 (E. T. Dumble, "Geology of East Texas," *Univ. Texas Bull. 1869*, pp. 186–87), the following statement appears.

"Therefore, no traces of any marine deposits referable to the Vicksburg have been found in East Texas, nor is there any indication that the sandstones overlying the Jackson and referred to the Oligocene are, in any part, representative of Vicksburg time. Such deposits, however, may exist to the seaward and be overlapped by the later beds."

Though the fossils obtained from the Humble Lovejoy No. 1 at West Columbia were recognized at the time to have lower Oligocene affinities, as a matter of fact they were actually called Jackson, and referred to the Jackson stage.

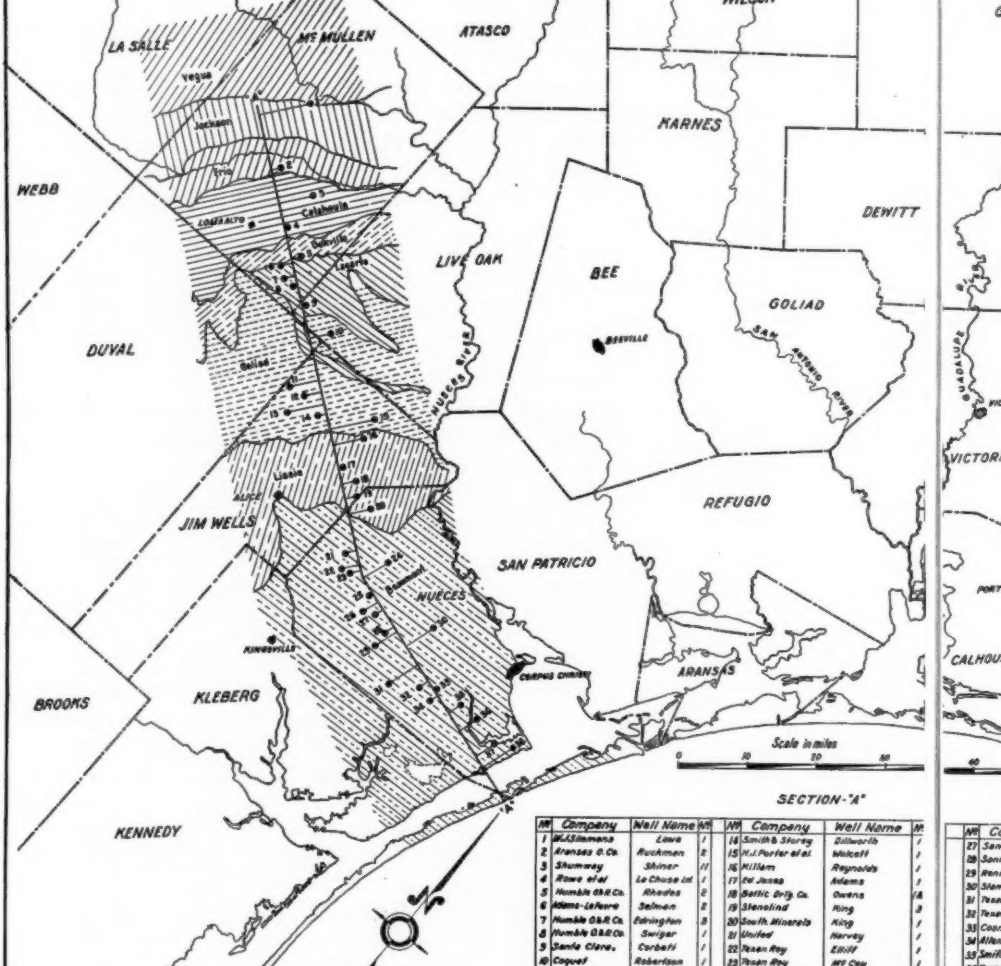
The first definite identification of Vicksburg fossils in the subsurface of Texas, so far as the writers have been able to ascertain, was that made of some microscopic fossils obtained from the well, Humble-Rycade's Kountz No. 3, at Markham, Matagorda County, in 1927.

It was not until 1933, however, that the first published record was made of the occurrence of Vicksburg in the underground of the Texas Gulf Coast. This appeared in the paper by Alva C. Ellisor, "The Jackson Group of Formations in Texas with Notes on Frio and Vicksburg," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 11 (November, 1933), pp. 1321–25.

[8] The marine Miocene is only sparsely developed in that part of the Gulf Coast reviewed in the present study—it attains a prominent position in the subsurface stratigraphy in the Mississippi delta region of East Louisiana, and unquestionably attains a very considerable thickness farther out in the geosynclinal basin, beneath the sea adjacent to that part of the Gulf Coast area here considered. Furthermore, electric records of this portion of the wells in the area here reviewed are at the present time not available, making it impossible to correlate individual sand and shale members by this method—for these several reasons no further detailed description of the Miocene will be attempted in this paper.

[9] Alexander Deussen, "Geology and Underground Waters of the Southeastern Part of the Texas Coastal Plain," *U. S. Geol. Survey Water-Supply Paper 335* (1914), map, Pl. I.

[10] *Idem*, "Geology of the Coastal Plain of Texas West of Brazos River," *U. S. Geol. Survey Prof. Paper 126* (1924), Pl. VIII.



No.	Company	Well Name	No.
1	W.J.Simmons	Lowe	1
2	Aransas O. Co.	Ruckman	2
3	Shumway	Shiner	11
4	Rowe et al	Le Chuse Ltd	1
5	Humble O&R Co.	Rhodes	2
6	Adams-Lefevre	Salmon	2
7	Humble O&R Co.	Edrington	3
8	Humble O&R Co.	Swigar	1
9	Santa Clara,	Corbett	1
10	Coquet	Robertson	1
11	Trinity Drlg. Co.	Schaeffer	1
12	Maher & Shire	Schaeffer	1
13	South Minerals	Hawkins	1
14	Smith & Storey	Dillworth	1
15	H.J. Porter et al.	Wolcott	1
16	Killam	Reynolds	1
17	Ed Jones	Adams	1
18	Baltic Drlg. Co.	Owens	1A
19	Stanolind	King	3
20	South Minerals	King	1
21	United	Harvey	1
22	Texan Roy	Elliff	1
23	Texan Roy	Mc Coy	1
24	B.M. Richardson	Gerhardt	1
25	Hinds et al	Rivers	1
26	Hinds	Fiala	1

FIG. 1.—Map of part of Gulf Coast of Texas, between Colorado and Nueces rivers,

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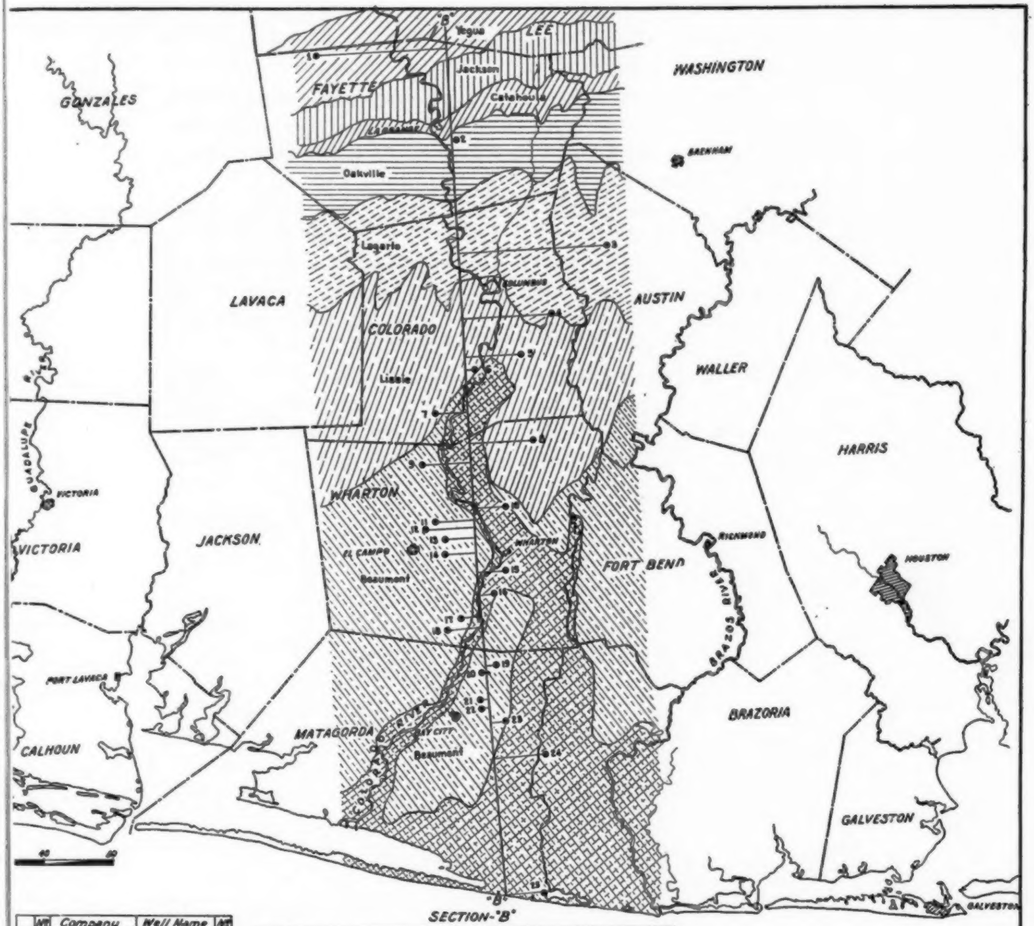


	Nº	Company	Well Name	Nº
	27	Santa Clara	Driscoll-Sevier	A-1
	28	Santa Clara	Cooke	1
	29	Renwar	Willoughby	1
	30	Stemex O&G Co.	Bird	1
	31	Texas Seaboard	Schaeffer	1
	32	Texas Seaboard	Chapman	1A
	33	Conner	Stockton	1
	34	Allen-Seaboard	Chapman	B-1
	35	Smith & Richardson	Carter	1
	36	Terminal Prod. Co.	Thurman	1
	37	Cullen	Singer	1
	38	Hurlburt et al	Phillips	1

Nº	Company	Well Name	Nº
1	Teas	Vinklarek	1
2	J.E Thomas	Glecker	1
3	Hargrove-Cockburn	Bartay	1
4	Trans-State	Witte	1
5	Humble O&R Co.	Relaw	1
6	Eden Oil Co.	Wells	1
7	Denciger Oil Co.	Raver	1
8	Straka Pet.	Strunk	1
9	Navarro Oil Co.	Sheeman	1
10	Falmont	Mitchell	1
11	Smith & McDonald	Priesmeyer	1
12	Smith & McDonald	Martin	1
13	Texas Co.	Marek	2

Nº	Company	Well Name	Nº
14	Texas Co.	Pierce	33A
15	Shell Pet. Corp.	Snyder	1
16	Cockburn et al	Neal	1
17	Texas Co.	Pierce	1C
18	Pure Oil Co.	Borden	1
19	Pierce Estate	Fee	1
20	Pierce Estate	Fee	2
21	Shelly Oil Co.	Cobb	1
22	Shelly Oil Co.	Turner	1
23	Royal Oil Co.	Ewing	1
24	Harrison-Abercromby	B.R.L.D	4
25	Straka Pet.	Sargent	1

Portion of the Texas Gulf Coast between Colorado and Nueces rivers, showing location of the sections, and of the wells utilized in the construction of the sections –
By Alexander Deussen & Kenneth Dale Owen

rivers, showing location of sections, and of wells used in construction of sections.

4,000 feet. The sections were commonly made on a small scale and were purposely generalized.

Refinement in methods of geologic study has made such notable progress during the course of 20 years that it is now possible to offer some sections that show detail, accuracy, and depth in a manner undreamed of 2 decades ago.

Advances in methods of geologic study have been made possible because the oil operator has now adopted the practice of taking numerous cores of the formations as he drills through them, and because he is now drilling wells to a depth of 12,000–13,000 feet. Cores are actual samples of the formations penetrated and their exact depth is known.

Since about 1922 systematic study has been made of the foraminifera obtained from cores and well cuttings. These microscopic fossils are not destroyed in the drilling process, and are therefore more readily and more easily obtained than the large fossils. It is been found that single species of foraminifera in some places, assemblages in others, are diagnostic, and can be confidently used for correlation of identical faunal zones in wells.

In 1933 there was introduced into the Gulf Coast the electric log, which has now become a matter of routine operation. These logs, by giving a mechanical silhouette pattern of the lithologic composition of the formations encountered in wells, when aided by the known position of some definite horizon determined from the micro-fossil content, make it now a comparatively simple matter to correlate formations. By means of the electric log it is possible to identify and trace individual sand and shale members from well to well, and commonly for considerable distances. As long as it was necessary to rely on the ordinary driller's log, it was thought that most of these sands and shales were very limited and local in extent, and it was almost impossible to correlate any sand member for a significant distance. Many wells drilled within a few feet of each other, and even in side-tracked holes, showed little or no correspondence of beds when the drillers' logs were utilized.

With the data now available the writers have prepared two sections of the Gulf Coast to show the detail of the underground to a depth of 12,000 feet.

Location of these sections is shown in Figure 1.

The east, or *BB*, section extends from the outcrop of the Yegua formation in Fayette County, to a point on the coast, east of Matagorda, in Matagorda County. The west section, *AA*, extends from the outcrop of the Yegua formation in McMullen County, to a point

on the coast at Flour Bluff, at the southwest corner of Nueces County. The formations at the surface along the line of each section are shown in Figure 1.

EAST SECTION, BB

The east section is shown in Figure 2.

YEGUA FORMATION

The lowermost of the formations with which we are concerned in these sections is the Yegua, with the Cockfield member at the top. Where the Yegua is exposed in Washington and Fayette counties, it consists largely of shale and clays with some interbedded sands and lignites, and in a few places contains some shales with a sparse marine fauna. The outcrop section has been described by the senior writer and others.[11]

The Yegua is primarily a continental deposit, with sands of fluviatile origin, peats of swamp origin, and clays of lake origin—these swamps and lakes having lain inland from, and adjacent to, the shore line which was south of the present outcrop area.

The northernmost well of this section (Teas, Vinklarek No. 1) began in the Yegua. Unfortunately, no electric log was made of the first 500 feet penetrated in this well, which would have described electrically the character of these beds in the outcrop.

The second well in the section, about 16 miles south, encountered the Yegua between approximately 1,200 and 2,200 feet below sea-level. Here the electric log records mainly calcareous clay and calcareous sandy clays. No marine fossils are recorded from this well.

In the third well of the section (Hargrove and Cockburn, Bartay No. 1), in Colorado County, the top of the Yegua was encountered at approximately 3,500 feet below sea-level. A few thin sands are shown by the electrical record, but here the formation has lost much of its lime and very little lime appears thereafter as the formation is traced downdip in the several wells.

Also the first foraminifera, indicative of marine conditions, appear in this well—*Discorbis yeguaensis*—indicating that between this well and the one on the north, No. 2 (J. E. Thomas, Glecker No. 1) the continental deposits of the outcrop Yegua are grading downdip into shales and a few interbedded sands of marine origin.

The southernmost well in which the Yegua was encountered in this section was No. 10 (Felmont, Mitchell No. 1) in Wharton County.

[11] Alexander Deussen, "Geology of the Coastal Plain of Texas, West of Brazos River," *U. S. Geol. Survey Prof. Paper 126* (1924), pp. 75–80.
E. H. Sellards, W. S. Adkins, and F. B. Plummer, "The Geology of Texas," Vol. I, "Stratigraphy," *Univ. Texas Bull. 3232* (August 22, 1932), pp. 666–77.

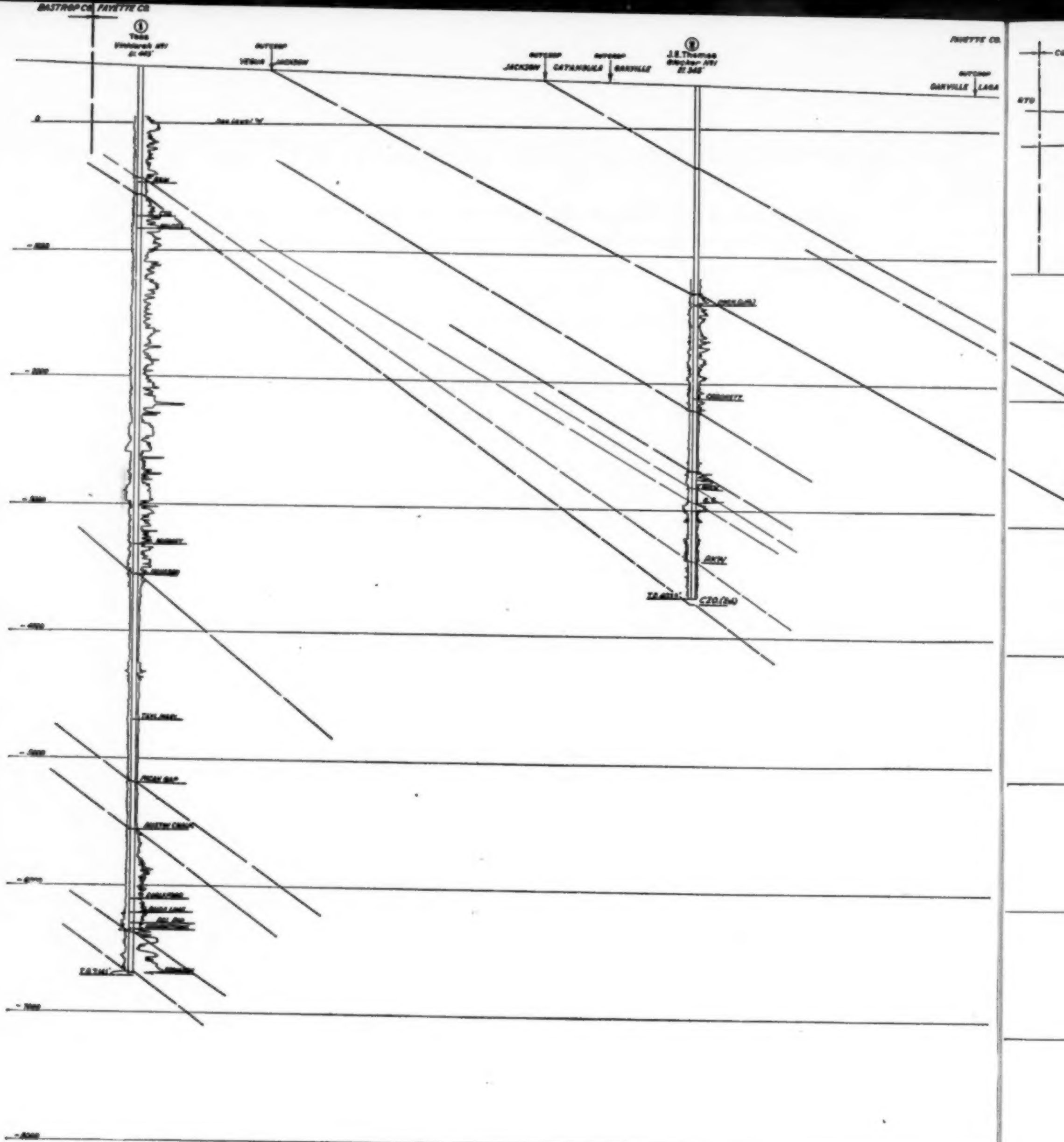
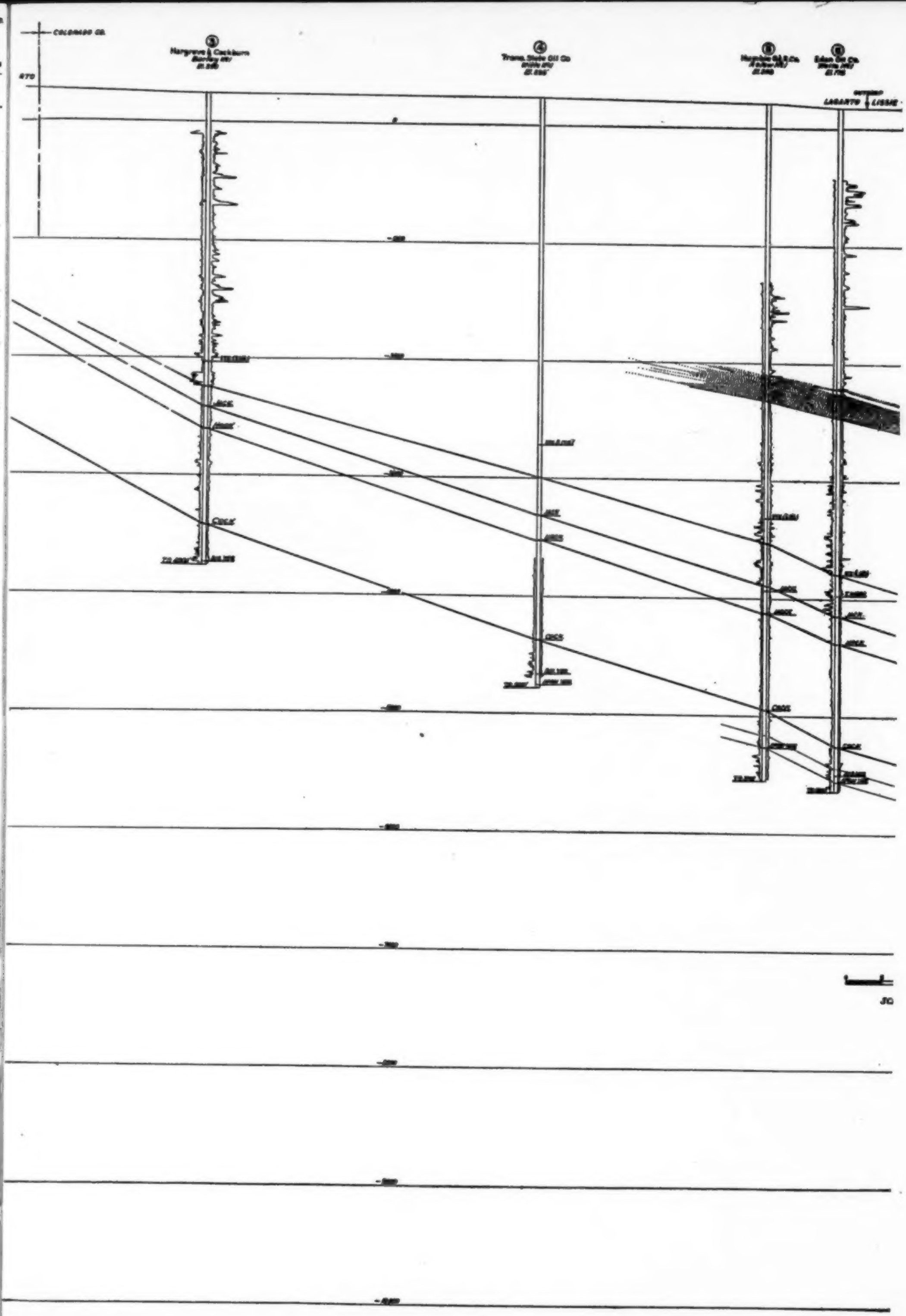


FIG. 2.—Geologic section of Texas Gulf Coast from La Grange, Fayette County,



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County, to point on coast east of Matagorda, Matagorda County.

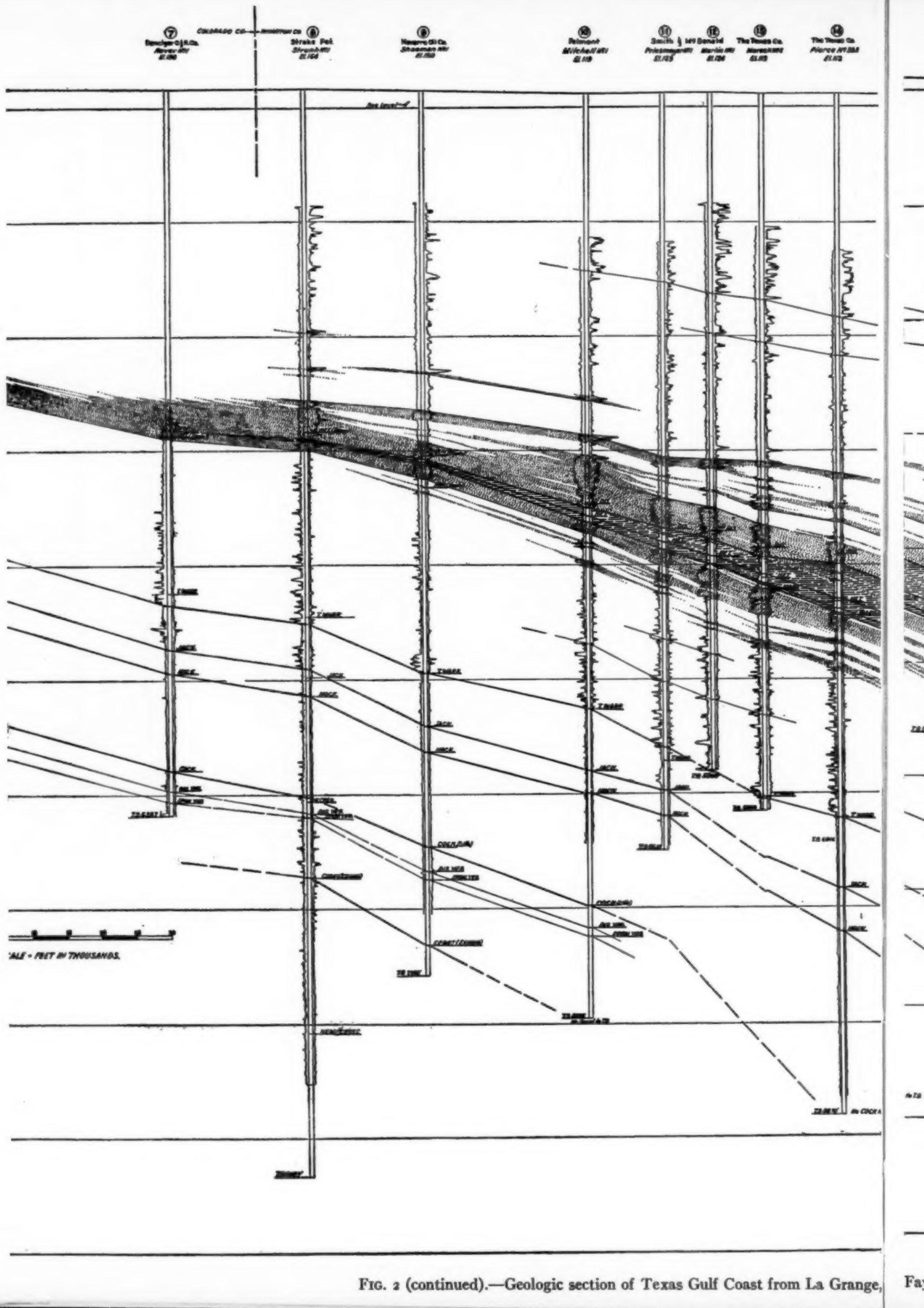
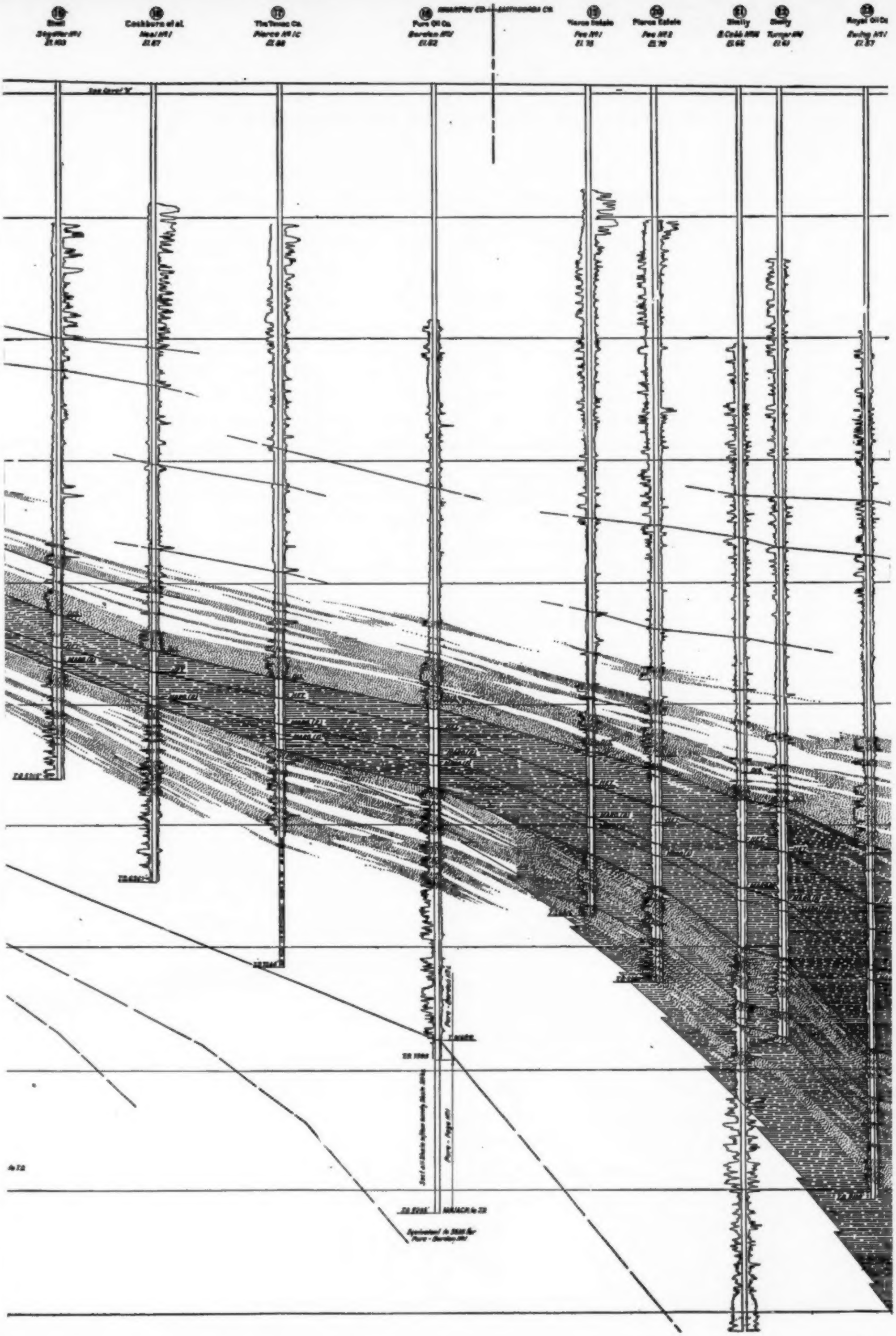


FIG. 2 (continued).—Geologic section of Texas Gulf Coast from La Grange, Fa

Grange,



Fayette County, to point on coast east of Matagorda, Matagorda County.

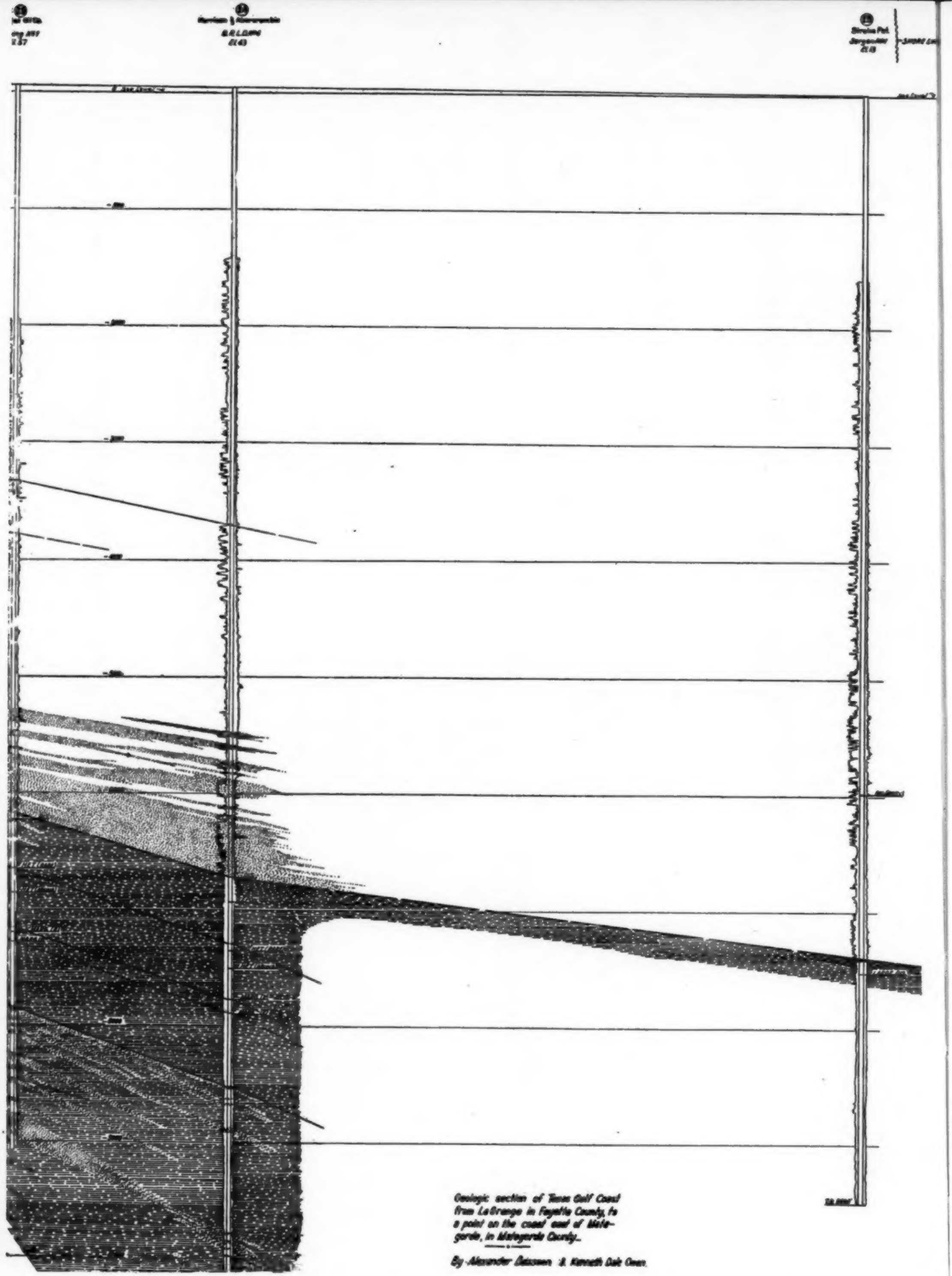


FIG. 2 (concluded).—Geologic section of Texas Gulf Coast from LaGrange, Fayette County, to point on coast east of Matagorda, Matagorda County.

It entered the Yegua at a depth of 7,000 feet below sea-level. No electric record is available which shows the lithologic character here. However, in the well immediately north, No. 9 (Navarro, Shoeman No. 1), in Fort Bend County, the electric record shows the Yegua to consist almost entirely of impervious shale, the sands of the upper part of the formation having completely disappeared this far downdip.

From its first appearance updip in well No. 3 in Colorado County, *Discorbis yeguaensis* continues downdip in all of the wells of this section which entered the Yegua. *Eponides yeguaensis*, which characterizes a lower horizon of the Yegua than the *Discorbis yeguaensis*, appears first in well No. 4 in Colorado County and repeats downdip in all the other wells of this section which entered the Yegua. *Ceratobulimina eximia* characterizing a still lower horizon, appears first in the northernmost of the three southernmost wells of this section, which have penetrated the Yegua. It is recorded in wells 8 and 9 in the north part of Fort Bend County.

So far as the Yegua is concerned, therefore, this section definitely shows the sands, clays, and lignites of non-marine origin grading downdip into a series of shales and clays of marine origin. The shore line of the Yegua sea evidently reached as far north as well No. 3, five or more miles north of Columbus in Colorado County, and north of this shore line there was evidently a series of swamps, lakes, and lagoons as far north as the present location of Fayette County in which were deposited the sands and clays, and lignites, such as are known in the outcrop Yegua.

JACKSON FORMATION

The Jackson formation where it crops out in Fayette and Washington counties, consists mainly of sands and sandstones with some interbedded clays and shales, and sandy clays. The sandstones contain casts of marine fossils, indicating the presence of marine conditions as far inland as the present outcrop area.

It has been previously indicated that the shore line during the deposition of the Yegua was somewhere between the locations of wells 2 and 3, and near the present south boundary line of the Oakville formation (Fig. 1). On the basis of the fossils in the Jackson it appears that following the deposition of the continental Yegua beds, the lakes and swamps in which these beds were deposited were depressed and invaded by the sea, and the shore line moved 20–30 miles north into the present area of Fayette and Washington counties.

The first electrical record of the formation in the section downdip

is that shown in well No. 3 (Hargrove-Cockburn, Bartay No. 1), in Austin County, where it was encountered at a depth between 2,500 and 3,500 feet below sea-level, approximately 1,000 feet in thickness. Here it consists mainly of shale and clay with only a few thin sand beds. It continues to display the same electrical character in all of the wells as the formation is followed downdip and it can be readily recognized in the electrical logs, even without the aid of the fossils.

The characteristic foraminifer, *Textularia hockleyensis*, appears in all of the wells with the exception of the one nearest the outcrop, No. 2, and occupies a definite and persistent plane in the formation 200 feet below the top.

The dip of the top of the formation is more or less uniform from the outcrop as far south as well No. 14 (Texas Company, Pierce No. 334), and in this distance of approximately 56 miles it drops from an elevation of 500 feet above sea-level to 6,800 feet below sea-level, or a total drop in this interval of approximately 7,300 feet, the dip being at the rate of 130 feet to the mile. Parenthetically it may be added that the accurate determination of the dip is one of the valuable features of the present sections.

Examination of this top surface in the section will show the ease with which it can be recognized. It is therefore a valuable datum plane for subsurface contouring in that part of the Gulf Coast where it is reached in these wells—a band 60 miles wide extending south from the outcrop area and to a boundary within a distance of 30 miles from the present shore line.

South of well No. 16, approximately 8 miles south of well No. 14, this formation begins to plunge downward, and likewise thicken, this being the approximate north limit of the geosynclinal basin which is more fully discussed in connection with the overlying Oligocene formations.

OLIGOCENE

Overlying unconformably the Jackson on the outcrop in the line of the east section is the Catahoula, a formation consisting of sands and clays with large quantities of silicified wood, some plant remains, and large quantities of volcanic ash. There are no marine fossils.

In South Texas and along the line of the west section, the Catahoula rests unconformably on the Frio clay, which in turn lies on top of the Jackson. Apparently between the two sections the Frio disappears by reason of overlap of Catahoula on Jackson.

As shown in the east section there is not more than 300 feet of formation in well No. 2 (J. E. Thomas, Glecker No. 1) in Washington County, from 50 feet above to 250 feet below sea-level, that can be

assigned to the Catahoula. Unfortunately, for this well no electrical record of the Catahoula lithology is available.

At the surface in the line of the east section in Washington and Fayette counties, the Catahoula is overlain (also unconformably) by the Oakville sandstone, a formation which contains vertebrate fossils of Miocene age.

Approximately 100 miles south at well No. 24 (Harrison and Abercrombie, Bernard River Land Company No. 4), the base of the Miocene is 5,500 feet below sea-level,[12] and no Jackson is found to the total depth of 10,775 feet.

According to the electrical log, at the base of the Miocene, there is a series of sands 1,200 feet in thickness, and below this a body of marine shale 3,500 feet in thickness, and below this 200 feet of sand, which contains the oil and gas in the Old Ocean field.

This marine shale member, 3,500 feet thick in the Harrison and Abercrombie well (No. 24 on Fig. 2), represents the Oligocene marine shale wedge, a part of marine Oligocene wedge, of which there was the first evidence when lower Oligocene fossils were identified for the first time from the Humble Oil and Refining Company's Lovejoy No. 1 at West Columbia in 1923.

The electrical logs trace with a striking degree of consistency the sand member at the base of the Miocene, overlying the marine shale member, as far updip as well No. 9 (Navarro Oil Company, Shoeman No. 1) in the northeast part of Wharton County, where it is replaced by calcareous clay or marl, and this calcareous clay or marl can be traced updip in the electrical logs as far north as well No. 5 (Humble Oil and Refining Company, Relaw No. 1), south of Columbus, Colorado County.

Likewise, below the marine Oligocene shale wedge is a very thick series of sands, typically displayed in well No. 21 (Skelly Oil Company, Cobb No. 14-B), at Van Vleck, Matagorda County, here shown between 8,100 and 11,000 feet below sea-level, approximately 2,900 feet in thickness.

This sand series below the shale member can be readily traced updip by means of the electrical logs, thinning meanwhile, as far north again as well No. 8 (Strake Petroleum, Inc., Strunk No. 1), in the northern part of Wharton County.

The lower sand series is what has been designated in the subsurface as the "Frio sand," and is the producing zone of several oil fields discovered in the Gulf Coast during the past 6 or 7 years, for example, Anahuac, Van Vleck, Bay City, Hastings, and Friendswood.

[12] The contact may be as deep as 6,000 or even 6,800 feet.

Below the lower sand series, or the subsurface "Frio," the electrical logs show another bed of shale or clay, with a few thin sand members as the updip wells are reached, and paleontologic study shows that this shale member contains the foraminifer, *Textularia warreni*, a fossil characteristic of the Vicksburg.

The Vicksburg formation can therefore be easily traced by means of both the fossils and electrical character, from well No. 21 at Van Vleck, Matagorda County, to well No. 6, south of Columbus, Colorado County.

No *Textularia warreni* occur in the subsurface, north of well No. 6 and control is very limited north of this well. However, lithologic study of the well samples indicates Vicksburg characteristics in well No. 4 at approximately 2,700 feet below sea-level, and in well No. 3 at approximately 2,000 feet below sea-level.

Farther updip, to the surface, we find that the only beds that occupy in part the same time interval as all of these Oliogcene beds of more than 4,000 feet in thickness, recorded in the Harrison and Abercrombie, Bernard River Land Company No. 4 in Brazoria County, are the Catahoula beds, barely 300 feet in thickness, in well No. 2 (J. E. Thomas, Glecker No. 1), Washington County.

The question is, so far as the east section is concerned, what part of the subsurface Oligocene displayed in well No. 24 (Harrison and Abercrombie) and well No. 21 (Skelly, Cobb No. 14-B) does the surface Catahoula represent?

By examination of the section, with Vicksburg lithologic characteristics indicated in well No. 3 at 2,000 feet below sea-level, it might seem that this Vicksburg could be traced directly into the Catahoula at the surface.

When a sufficient number of electric logs become available to fill in the gaps in this section between well No. 6 (northernmost *Textularia warreni*) and the outcrop, the writers have little doubt that a definite answer can be given this question.

The implications of some of the facts here indicated from the standpoint of the geologic history of the Gulf Coast, are stated in the following paragraphs.

The marine Oligocene shale wedge, as pointed out, has a thickness of more than 3,500 feet. It thins northward and disappears completely in well No. 7 (Danciger, Raver No. 1) in the southeast corner of Colorado County.

It is underlain by a sand series and overlain by a sand series, readily traceable from the electric logs.

The lower part of the shale is characterized by the presence of the

foraminifer, *Marginulina mexicana* var. *vaginata*, and farther updip this fossil continues to occupy the lower part of the shale as far north as well No. 17 (Texas Company, Pierce No. 1-C) in the southern part of Wharton County.

The lower shale, with *Marginulina mexicana* var. *vaginata*, is overlain by another shale member, characterized by the presence of the foraminifer, *Marginulina idiomorpha*, and this shale member with this fossil, continues updip as far north as well No. 14 (Texas Company, Pierce No. 33-A) in central Wharton County. It should be observed that this member with *M. idiomorpha* extends farther inland, and north of the shale member with the *M. mexicana* var. *vaginata*.

Above the shale members with *M. idiomorpha* in well No. 24 (Harrison and Abercrombie) occurs another shale member characterized by the foraminifer, *Heterostegina texana*, and this continues updip as far north as well No. 10 (Felmont, Mitchell No. 1) in Wharton County. Again it should be observed that this member extends farther inland, and north of the member with the fossil, *Marginulina idiomorpha*.

Above the last-named member, occurs another shale member in well No. 24 (Harrison and Abercrombie) characterized by the presence of the foraminifer, *Discorbis* sp. This likewise continues northward until it disappears by thinning where well No. 10 (Felmont, Mitchell No. 1) is reached.

The northern limit for the occurrence of these several fossils, including *Textularia warreni* of the Vicksburg, is shown in Figure 1.

It appears that at the close of the Eocene following the deposition of the Jackson, all of the present area of the Gulf Coast was elevated above sea-level and subjected to erosion, as evidenced by the unconformity at the surface between the Catahoula and the Jackson.

Following this land and erosion epoch, there was a fairly rapid submergence of the present Gulf Coast area with an advance of the sea as far north as the line shown in Figure 1, as the upper limit of the *Textularia warreni*, extending from Alice, Jim Wells County, to a point south of Columbus, Colorado County, and during this period, the marine shales of the Vicksburg were deposited.

Following the period of Vicksburg deposition there was again another somewhat rapid retreat of the sea, and the lower part of the sand formation designated as the subsurface "Frio" in this section may record this retreat.

Following this period came another in which the sea again gradually advanced northward, and this advance is recorded by the upper part

of the sand series designated as the subsurface "Frio," an advancing strand line.

While this was occurring there was a gradual sinking of the sea floor in the lower area of the present Gulf Coast, occupying a part of the present area of Matagorda County, this being the northern limit of the deep basin which Barton, Ritz, and Hickey have described as the Gulf Coast geosyncline.[13]

Into this basin were dumped the muds which now form the marine shales recorded in well No. 24 (Harrison and Abercrombie).

As the basin continued to sink, the shore with its advancing strand line continued to move northward. Near the close of Oligocene, the northern limit was reached, this being marked by the line in Figure 1 shown as the upper limit of the *Heterostegina texana*, this being the north limit of marine deposition.

The shore line at this time did not reach a position as far north as that obtained by the Vicksburg sea, since the line marking the upper limit of *Textularia warreni* is 10–12 miles north of the line marking the upper limit of the *Heterostegina texana*.

There is a considerable bit of evidence concerning many of the salt domes in the Gulf Coast that their first movements may have begun in early Oligocene time following the deposition of the Vicksburg; many of them, on the basis of missing beds, appear to have been islands in the Oligocene or post-Vicksburg sea, and it may well be that the loading in the geosynclinal basin that took place when this great thickness of sediments, represented by the Oligocene wedge, was poured into it, resulted in the extrusion of the lighter-bedded salt from the more deeply buried beds to form the salt stocks now known as the salt domes.

Following this advance of the sea came another period of retreat and uplift in the basin area. This retreat is recorded by the series of sands shown in the electric logs as lying above the marine shale. They contain in part the *Discorbis* fossils.

This particular series of sands represents the retreating strand line at the close of the Oligocene, although some of the upper members of this series might as easily represent the first invasion of the Miocene sea.

POST-OLIGOCENE BEDS
(FLEMING)

Above the sand series overlying the marine shale the electric logs very definitely record a series of clays and shales, calcareous in places,

[13] Donald C. Barton, C. H. Ritz, and Maud Hickey, "Gulf Coast Geosyncline," *Gulf Coast Oil Fields* (Amer. Assoc. Petrol. Geol., 1936), pp. 192–204.

with some thin irregular beds of sand. This member is approximately 1,500 feet in thickness, and can readily be traced from well No. 24 north to well No. 6 (Eden Oil Company, Wells No. 1), 10 miles south of Columbus, Colorado County. These clays are typically displayed from 2,000 to 3,700 feet below sea-level in well No. 15 (Shell Petroleum Corporation, Seydler No. 1), 2 miles south of Wharton, Wharton County.

These beds contain no marine fossils, but characteristically contain numerous specimens of reworked foraminifera of Cretaceous age. They are clays and shales deposited in lakes and fresh-water lagoons back of the shore line, then probably somewhere near the location of the present town of Bay City, Matagorda County. These are the Fleming beds and are traced into the Lagarto beds on the outcrop, which in places contain vertebrate fossils of Miocene and early Pliocene age.

POST-FLEMING BEDS

Because electric records of the beds comprising the upper 2,000 feet are not available for the several wells included in this section, no attempt is made in the present paper to correlate any of these upper members, or to discuss them. Unfortunately, heretofore it has been the practice to omit the electric record of the upper 2,000 feet, when electric surveys are made. Ordinarily the electric log is not run until a well begins to approach the depth at which oil might be expected and this is generally not done until the pipe in the upper part of the hole has been set, and so far it has not been found possible to record the electrical character of the formations through the pipe.

The writers have little doubt, however, that if enough of such electrical records were available, the upper members could be correlated with little difficulty, even in the absence of fossils.

WEST SECTION, AA

The west section is shown in Figure 3.

Inspection of this section shows the same depositional sequence as is recorded in the east section.

The marine Oligocene shale wedge, with the foraminifers, *Marginulina mexicana* var. *vaginata*, *Marginulina idiomorpha*, and *Heterostegina texana* in the same relative positions, is easily recognized. However, only the western attenuated edge of the shale wedge is present and there is no thickness of this shale in this section comparable with that which occurs in well No. 24 of the east section. The maximum thickness, as recorded in the southernmost well, No. 38

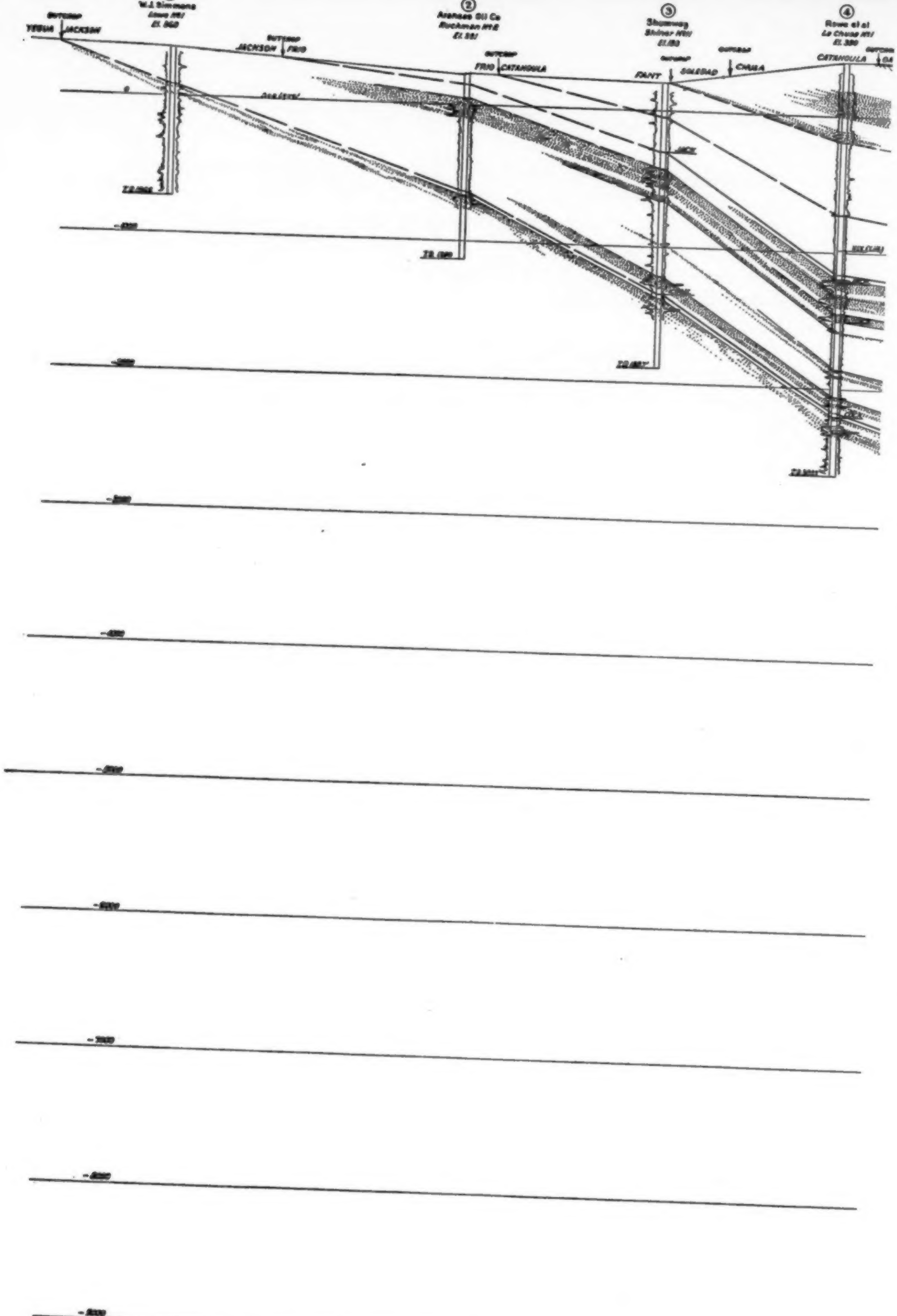
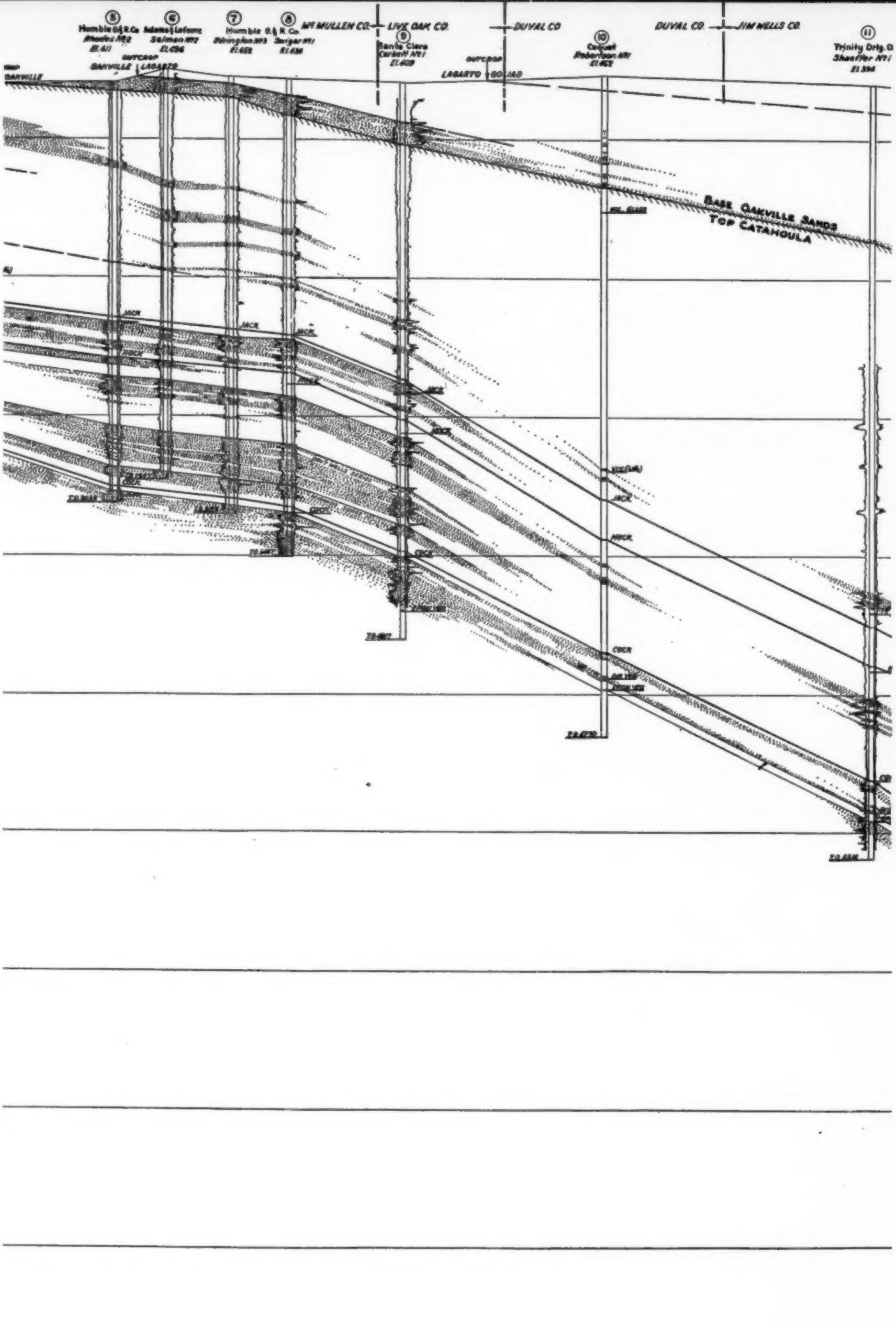


FIG. 3.—Geologic section of Texas Gulf Coast from vicinity



of Tilden, McMullen County, to Flour Bluff, Nueces County.

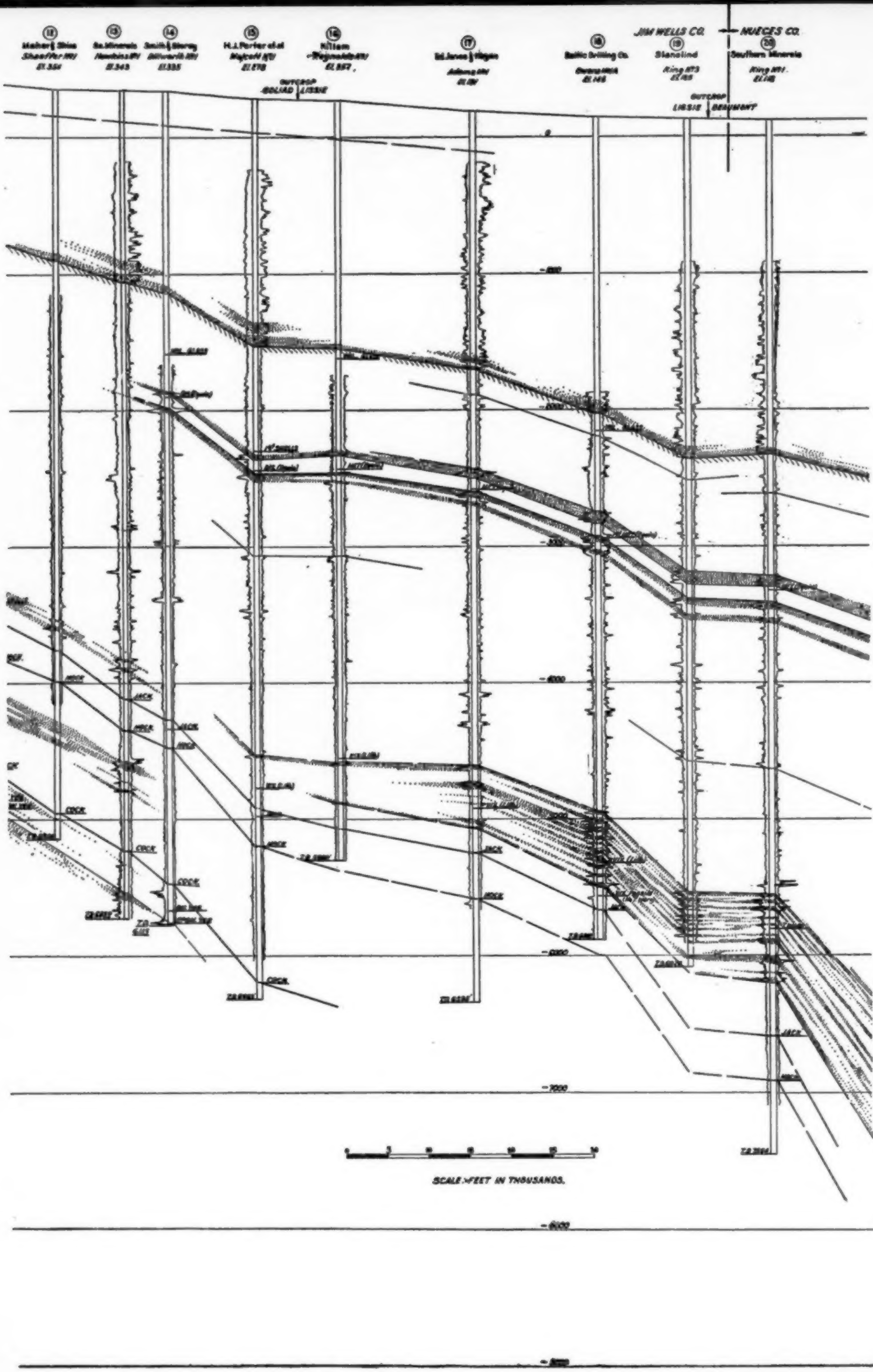
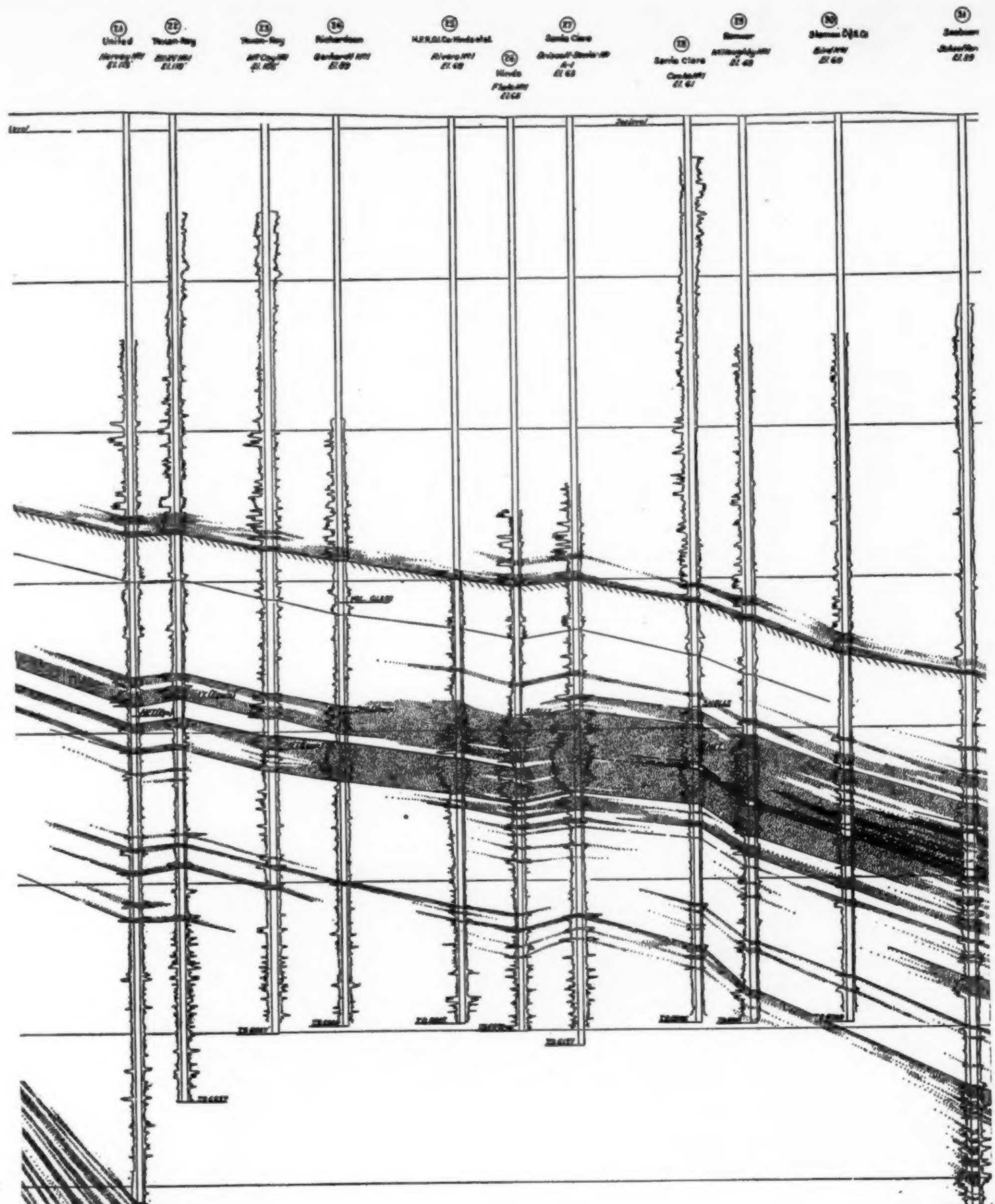


FIG. 3 (continued).—Geologic section of Texas Gulf Coast from



vicinity of Tilden, McMullen County, to Flour Bluff, Nueces County.

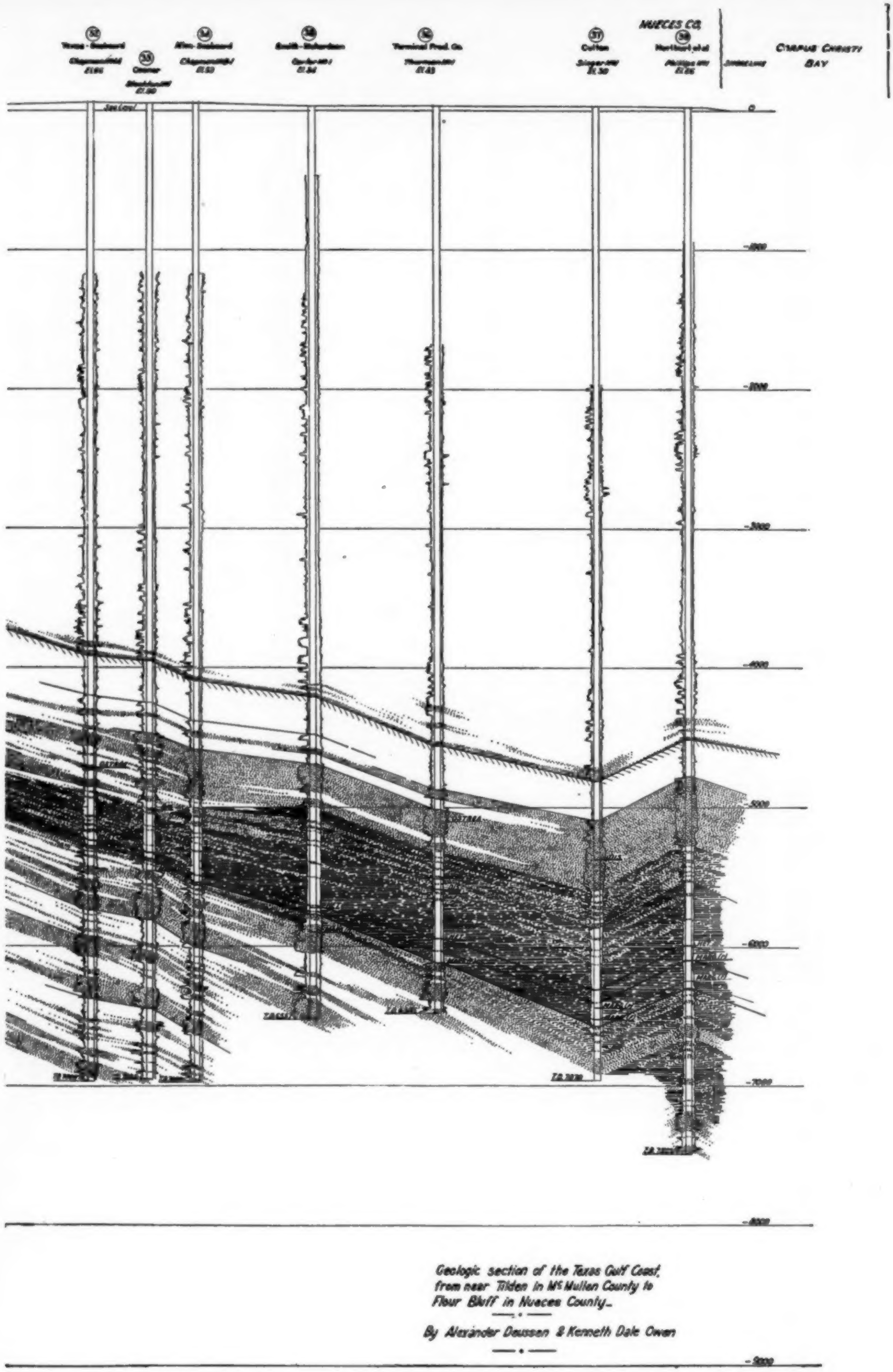


Fig. 3 (concluded).—Geologic section of Texas Gulf Coast from vicinity of Tilden, McMullen County, to Flour Bluff, Nueces County.

(Hurlburt *et al.*, Phillips No. 1), is not in excess of 1,000 feet, as contrasted with 3,500 feet in well No. 24 of the east section.

A comparable and presumably correlatable point in both sections is the upper limit of *Marginulina idiomorpha*, at a depth of approximately 5,500 feet below sea-level in well No. 34 (Allen-Seaboard, Chapman No. B-1), 15 miles from the present coast line, as against a depth of approximately 4,500 feet in well No. 14 of the east section, 45 miles distant from the present coast line.

The corresponding thickness of marine shale in the west section is probably farther in the basin and beyond the limit of the present coast line.

Attention was called in the east section to the increase in dip and downward plunge of the Jackson south of well No. 16. The same downward plunge and flexing, except on a much more pronounced scale, are observable in the west section south of well No. 20 (Southern Minerals, King No. 1), near the west line of Nueces County. Here the dip changes from 141 feet to the mile (on the Jackson as a datum, between wells 15 and 20) to 466 feet to the mile (on the Vicksburg as a datum between wells 20 and 21).

This line of post-Vicksburg flexing is unquestionably present in other sections between the two here shown, and is a prominent structural feature of this part of the Gulf Coast. Its location is shown in Figure 4. With it occur a number of faults mostly down on the south and up on the north, as might be expected, and these faults, together with subsidiary doming, are the cause of the group of oil and gas fields along this line, including Agua Dulce, Refugio, O'Connor, Tom O'Connor, Heyser, Placedo, and others.

As a result of this pronounced flexure in the area of the west section, developed after the deposition of the Vicksburg, the sands below the marine shale, the so-called subsurface "Frio," attain a very much greater thickness in the area of this section as compared with that of the east section.

There are no wells near the south end of the west section which have penetrated to sufficient depth to reach the bottom of the "Frio," but in well No. 21 (United, Harvey No. 1) in the western part of Nueces County, these "Frio" sands below the *Heterostegina* are approximately 3,100 feet in thickness, and the indications are that in the vicinity of well No. 31 (Texas Seaboard, Schaeffer No. 1), west of Corpus Christi, they may be 5,000 feet thick.

The electric logs of the Vicksburg between wells 18 and 21 near the west line of Nueces County and the northeast part of Jim Wells County, and at the upper limit of the marine phase of the Vicksburg

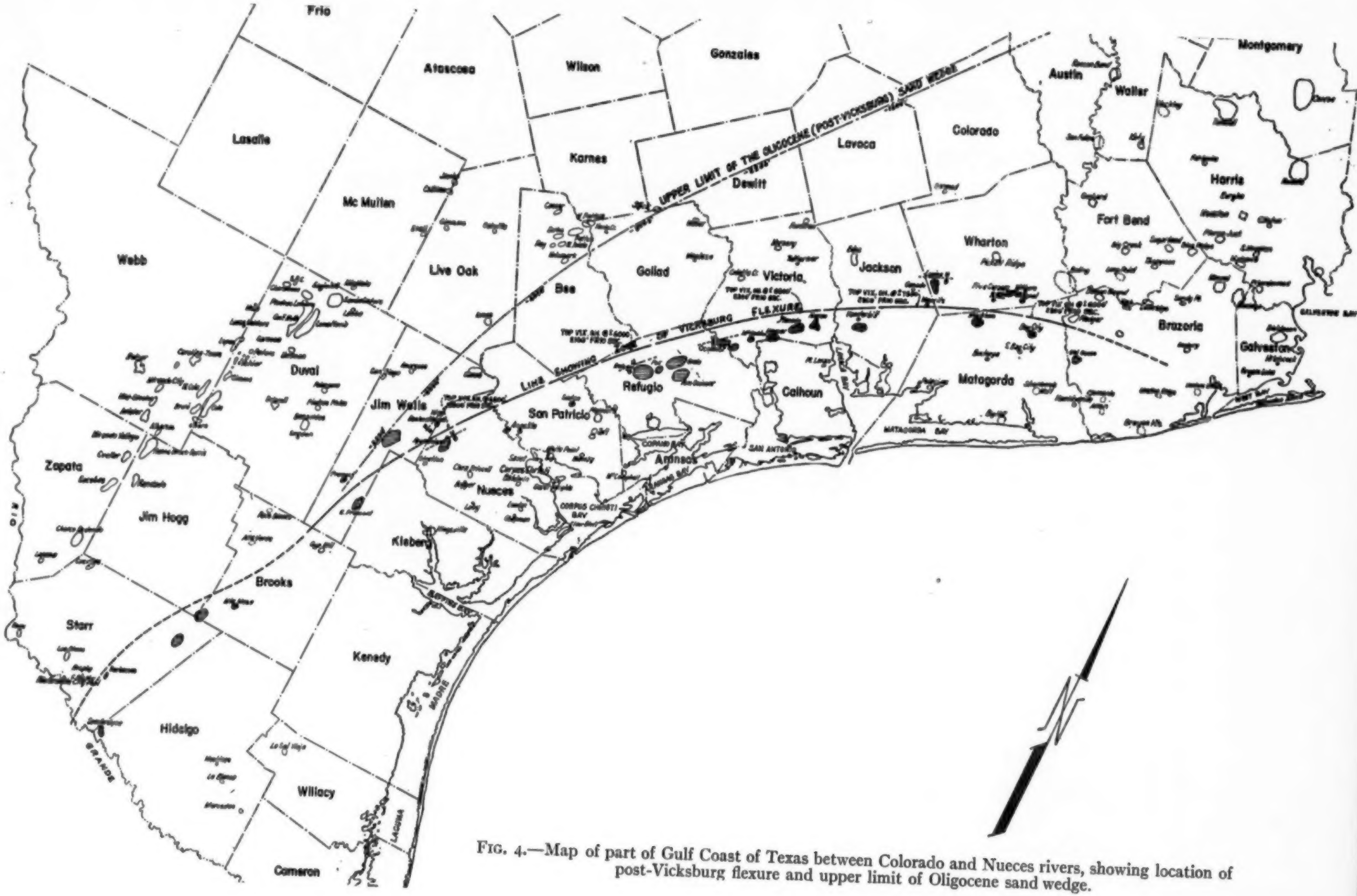


FIG. 4.—Map of part of Gulf Coast of Texas between Colorado and Nueces rivers, showing location of post-Vicksburg flexure and upper limit of Oligocene sand wedge.

(*Textularia warreni* present) show the presence of considerable sand in the formation, interbedded with calcareous clays and shales.

As more electric logs are available at the upper end of the west section, there is much better control in this area for tracing the subsurface beds into the outcropping formations.

The Jackson is readily traced from well No. 11 (Trinity Drilling Company, Schaeffer No. 1) in Jim Wells County to the outcrop in McMullen County.

To be noted in this connection is the flattening of dip or terracing that appears between well No. 4 (Rowe *et al.*, La Chusa Ld. No. 1) in McMullen County and well No. 8 (Humble, Swigar No. 1), 10 miles farther south along the section, a continuation of the same effect observable in the same belt farther south in Duval County.

The several sand members of the Jackson formation—Cole at the top, Loma Novia, and Government Wells, with the Mirando at the base—are excellently displayed in the electric log of well No. 9 (Santa Clara, Corbett No. 1) in the southwest corner of Live Oak County.

These several sand members are easily identifiable and traceable in the wells on the west, each of them thinning toward the west and disappearing at varying distances, the Cole series extending farther west, the lower or Mirando extending a lesser distance west, and the intermediate Government Wells series extending the least distance west.

At the attenuated west edge of these sands in many places in Duval and Webb counties, oil and gas accummulations occur, for example, at Government Wells in Duval County, and at Lopez, in Webb County.

In the area of the west section, as previously pointed out, the Frio formation crops out between the Jackson west of it, and the Catahoula east of it, this formation being absent in the surface section of the east cross section.

The Frio on the outcrop in McMullen County consists largely of massive clays with considerable quantities of secondary gypsum and selenite; and in places numerous beds of large fossil oysters, identified as *Ostrea georgiana*, occur.

Textularia warreni, of course, does not extend to the surface, disappearing north of well No. 18 (Fig. 1), but the stratigraphic implications of the west section indicate that the Vicksburg in the subsurface here is the time equivalent of the Frio in the surface section.

The electric logs show the Frio to be typically clay (record of wells 3, 4, 5, 6, 7 and 8) where the Frio is correlated readily from the silhouette pattern.

A sand member appears in well No. 9 and sand continues to increase thereafter in the section downdip. Here is an example of a clay formation being replaced downdip by a sand formation, the former probably deposited in quiet bays back of the coast, the latter, as evidenced by *Textularia warreni*, being sands deposited by wave and storm action in deeper water along the coast.

In the west section, unlike the east section, there is one datum

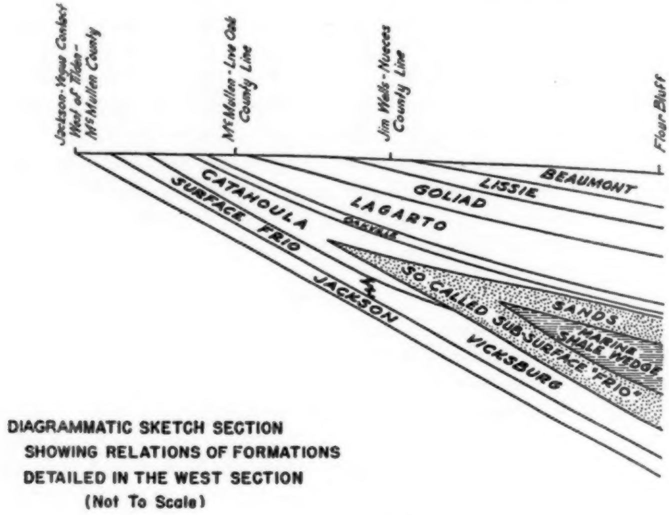


FIG. 5.—Diagrammatic sketch section, showing relations of formations detailed in west section *AA* (not to scale).

plane that can be traced through from the surface without question by means of the electric records and sample lithologic study. This is the contact of the Oakville on Catahoula, a break represented by the Miocene-Oligocene unconformity. The electric logs record this break with a remarkable degree of uniformity throughout the length of the section.

Volcanic glass in the outcrop can be followed through in the well samples as far downdip as well No. 24 in the west edge of Nueces County, and from here south the electric logs show unmistakably the relation of the beds which contain the glass to the attenuated edge of the marine shale wedge with *Heterostegina texana*.

Updip from well No. 29 the *Heterostegina* sand can be traced with ease in the electric logs as a finger of sand which gradually thins until

it completely disappears at well No. 13 near the west line of Jim Wells County.

This finger of sand where it disappears, occurs 800 feet below the top of the Catahoula in well No. 14. It is here a thin sand approximately 50 feet thick and a part of a formation, which, by the electrical

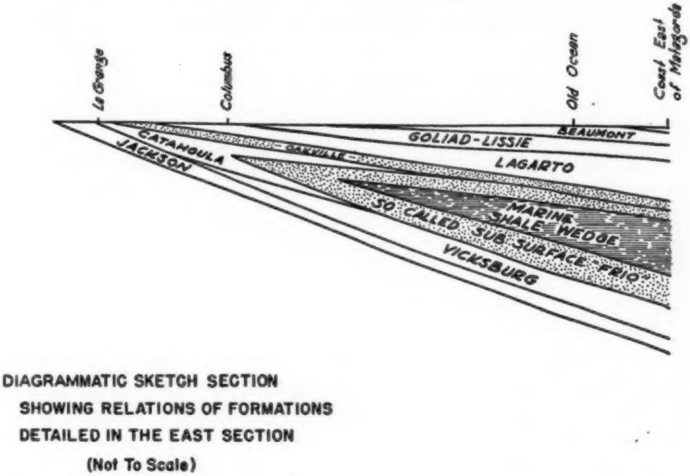


FIG. 6.—Diagrammatic sketch section, showing relations of formations detailed in east section *BB* (not to scale).

patterns, can be readily traced through to the outcrop into the Catahoula.

CORRELATION TABLE

Figures 5 and 6 are diagrammatic sketch sections, showing in more simple fashion the relations of the formations detailed in the west and east large sections, respectively (Figs. 3 and 2).

The correlation of the Frio and Catahoula has been one of the debatable questions of Gulf Coast geology for many years. The writers are not certain that they have the answer, but on the basis of this study the weight of evidence seems to point to the surface Frio as the outcrop time equivalent of the Vicksburg, both formations having been deposited under different conditions, the Frio in salt-water bays, back of the coast, and the Vicksburg in the open sea.

It is likewise apparent that the application of the name "Frio," on the assumption that it is the correlative of the surface Frio, to the thick body of sands below that member of the marine Oliogocene

shale containing the fossil, *Marginulina mexicana* var. *vaginata*, is a misnomer.

It likewise appears that the Catahoula is probably the surface time equivalent of the group of marine Oligocene beds, including the lower sands (subsurface "Frio"), the intermediate marine shale wedge, and the overlying sand series.

The marine Oligocene appears as a northward-thinning finger of marine formation which disappears north of the line marked as the upper limit of *Heterostegina texana* (Fig. 1, where it is replaced by the typical Catahoula beds, to the outcrop, a distance of 30–40 miles. Typical Catahoula beds overlie and underlie this marine wedge at its northern extremity and the Catahoula beds likewise wedge out as they are traced downdip to give way to the marine Oligocene.

Apparently while these marine sediments were being dumped into this basin in the open sea, there was back of the advancing and retreating shore linė a series of fresh-water marshes, lakes, and lagoons in which were deposited the sands and clays now referred to the Catahoula. Near the close of this epoch and near the beginning of the Miocene it is evident there was in the areas adjacent to the present Gulf Coast a very considerable amount of volcanic activity, as is indicated by the presence of large quantities of volcanic ash and volcanic glass in the upper part of these Catahoula beds.

It appears likewise that there are in the subsurface in the area embraced in this study at least four definite stratigraphic units, susceptible of easy recognition, in either the electric logs or the sample studies, that can be mapped by the customary methods of subsurface mapping, that are either not now named, or loosely named, or improperly named.

They are here listed.

1. The thick body of sands below the marine shale and above the Vicksburg, now commonly called the "Frio" in the subsurface (Figs. 5 and 6).

2. The marine shale itself characterized by the fossil, *Marginulina mexicana* var. *vaginata*, at the base, *Marginulina idiomorpha* above the preceding, *Heterostegina texana* above the latter, and *Discorbis* species near the top. This shale at the present time is not named (Figs. 5 and 6).

3. The thick body of sand above the marine shale and below the Fleming, or zone of reworked Cretaceous foraminifera, now loosely designated as the *Discorbis* (Figs. 5 and 6).

4. A sand unit north and west of the marine shale wedge and representing the merged western representatives of both the underlying

TABLE I
CORRELATION TABLE
POST-COOK MOUNTAIN FORMATIONS OF THE TEXAS GULF COAST BETWEEN THE COLORADO AND NUECES RIVERS

SERIES	GROUP	FORMATION	SURFACE WEST SECTION "A"-"A" NUECES RIVER	SURFACE EAST SECTION "B"-"B" COLORADO RIVER	SUB-SURFACE — WEST SECTION "A"-"A": WELL No. 21 WEST NUECES COUNTY				WELL No. 38 FLOUR BLUFF				SUB-SURFACE — EAST SECTION "B"-"B": WELL No. 10 NORTH OF WHARTON				WELL No. 24 OLD OCEAN			
					NAME	DEPTH Sub-Sea (Ft)	LITHOLOGY	FOSSILS	NAME	DEPTH Sub-Sea (Ft)	LITHOLOGY	FOSSILS	NAME	DEPTH Sub-Sea (Ft)	LITHOLOGY	FOSSILS	NAME	DEPTH Sub-Sea (Ft)	LITHOLOGY	FOSSILS
PLEISTOCENE		BEAUMONT LISSIE GOLIAD	BEAUMONT LISSIE GOLIAD	BEAUMONT LISSIE GOLIAD (?)																
UNCONFORMITY PLIOCENE-MIOCENE		LAGARTO	LAGARTO	LAGARTO																
		OAKVILLE	OAKVILLE	OAKVILLE	OAKVILLE	-2350 TO -2650	SANDS		OAKVILLE	-3900 TO -4500	SANDS									
UNCONFORMITY			UNCONFORMITY	UNCONFORMITY	CATAHOULA	-2650 TO -3600	CLAY WITH SOME SANDS Volcanic Glass		CATAHOULA	-4500 TO -4750	CLAY									
						-3600 TO -3900	SANDS			-4750 TO -5500	sands at top, sandy clay at [illegible]	DISCORBIS		-2800 TO -3450	SANDS	DISCORBIS AT BASE		-5450 TO -6650	SANDS	
OLIGOCENE	UPPER	CATAHOULA (SURFACE); MARINE OLIGOCENE WEDGE (SUB-SURFACE)	CATAHOULA	CATAHOULA	MARINE SHALE: MISSING, WEDGED OUT.					-5500 TO -6300	MARINE SHALE	HETEROSTEGINA AT -6000 a MARGINULINA (ROUND) AT -6100 b MARGINULINA (FLAT) AT -6225 c		-3450 TO -3575	MARINE SHALE	HETEROSTEGINA a		-6650 TO -10775 +	MARINE SHALE	DISCORBIS AT TOP; EPONIDES AT -6900; HETEROSTEGINA FROM -7350 TO -7450; a MARGINULINA (ROUND) AT -7700; b MARGINULINA (FLAT) AT -7850 c
					SUB-SURFACE "FRIO"	-3900 TO -7100	CLAYS WITH SOME SAND BEDS		SUB-SURFACE "FRIO"	-6300 TO -7500 +	SANDS, SANDY SHALES, AND SHALES		SUB SURFACE FRIO"	-3575 TO -5200	SANDS AND SANDY SHALES		NOT DRILLED INTO			
	LOWER	FRIO AT SURFACE; VICKSBURG IN SUB-SURFACE	FRIO CLAY	MISSING	VICKSBURG	-7100 TO -8500	SANDS AND SANDY CLAYS	TEXTULARIA WARRENI AT -8400'	NOT DRILLED INTO				VICKSBURG	-5200 TO -5750	MARINE CLAY	TEXTULARIA WARRENI AT -5200'	NOT DRILLED INTO			
UNCONFORMITY	JACKSON	WHITSETT OR FAYETTE MCELROY (T. HOCKLEYENSIS) CADDELL (T. DIBOLLENSIS)	UNCONFORMITY JACKSON	UNCONFORMITY JACKSON	JACKSON	-8500 TO -9008 +	SHALE		NOT DRILLED INTO				JACKSON	-5750 TO -6975	MARINE SHALE	TEXTULARIA HOCKLEYENSIS AT -6000'	NOT DRILLED INTO			
EOCENE	CLAIBORNE UPPER	COCKFIELD; UPPER SALINE BAYOU; LOWER SALINE BAYOU	YEGUA	YEGUA	NOT DRILLED INTO				NOT DRILLED INTO				COCKFIELD	-6975 TO -8075	NO RECORD	DISCORBIS [illegible] EPONIDES [illegible]	NOT DRILLED INTO			
	CLAIBORNE LOWER COOK MOUNTAIN	WILAMS CROCKETT SPARTA											NOT DRILLED INTO							
	CLAIBORNE LOWER MOUNT SELMAN	WECHES QUEEN CITY REKLAW (CANE RIVER); CARRIZO																		
	WILCOX	WILCOX																		
	MIDWAY	MIDWAY																		

a— Heterostegina texana   b— Marginulina idiomorpha   c— Marginulina mexicana var. vaginata

and overlying sand, described in the first and third preceding categories, and containing *Heterostegina texana* at its south or east end, but none at its attenuated north or west extremity (Figs. 5 and 6). It represents the innermost invasion of the advancing strand line of the Oligocene sea. This formation is now loosely referred to as the *Heterostegina*, although the same name is applied at times to zones containing *Heterostegina texana* farther downdip in the area of the marine shale wedge.

The writers offer the suggestion that the interested societies and organizations, for example, the Houston Geological Society, the San Antonio Geological Society, the Bureau of Economic Geology, at the University of Texas, and the United States Geological Survey, through accredited committees should agree on a nomenclature for these four units.

The writers might suggest, subject to the approval of the several organizations named, the name, Van Vleck sands, for the first unit to replace the name "Frio." This name is from the Van Vleck field in Matagorda County, where this sand is typically displayed in well No. 21 in the east section (Skelly, Cobb No. 14-B).

For the second unit, the name, Old Ocean shale, is suggested because of the typical development in the Old Ocean field of Brazoria County, as shown by well No. 24 in the east section (Harrison and Abercrombie, Bernard River Land Development Company No. 4).

For the third unit, the name, Pierce Estate sands, after well No. 20 in the east section in Wharton County (Pierce Estate, Fee No. 2), or Flour Bluff sand, after well No. 38 in the west section in Nueces County (Hurlburt and Still, Phillips No. 1).

For the fourth unit, the writers suggest the name, Driscoll-Sevier sand, because of its typical development in well No. 27 in the west section in Nueces County (Santa Clara, Driscoll-Sevier No. A-1).

In conclusion, the correlation of the formations disclosed in these sections is offered in Table I.

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AMELIA OIL FIELD, JEFFERSON COUNTY, TEXAS[1]

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ABSTRACT

The Amelia oil field, 5 miles west of Beaumont, Jefferson County, Texas, was discovered in 1936. Geophysical evidence of this structure led to the discovery but was rather indefinite as to true structural conditions. No surface geological indications of structure are present. The subsurface conditions are those of an elliptical, flat dome, probably underlain by a deeply buried salt core, and further complicated by a large normal fault striking almost parallel with the long axis of the dome. Amelia was one of the forerunners of a new type of coastal oil field, dominated by a big fault having production on the downthrown side while the upthrown side is dry.

The producing sand, locally known as the "Langham sand," is a member of the middle Oligocene Frio formation, and is found productive of oil and gas from 6,694 to 6,785 feet although only the last 20 feet shows oil. The sand is a thick, blanket sand body literally surrounded by salt water sands and has an extensive gas cap above the oil zone.

The field has a proved area of 1,220 acres and has produced 2,644,642 barrels of oil, to January 1, 1939, which gives an average of 2,168 barrels per acre. The present daily allowable under strict proration is 4,414 barrels from 115 producing wells. The Humble Oil and Refining Company operates 112 wells, or 98 per cent of the entire field, the only other operator being the Normandie Oil Corporation with three wells. Drilling development, on the basis of present known conditions, is entirely finished.

The development of this field was interesting, not only from the disclosure of its peculiar geological features, but also from the standpoint of unusually difficult well-completion problems. A new method of completing low gas-oil ratio wells employing squeeze-cementing was introduced at Amelia and has since been used extensively in other fields throughout the Gulf Coast region.

ACKNOWLEDGMENTS

The writer is indebted to the Humble Oil and Refining Company for granting permission to publish this paper. He is especially grateful to Morgan J. Davis and P. H. O'Bannon for their many helpful suggestions and criticism of the manuscript. Appreciation is also expressed to the various departments of the company whose coöperation lessened the difficulty of gathering the information included herein.

LOCATION

The Amelia oil field is located within the salt-dome province of the Gulf Coast of East Texas (Fig. 1). It is in Jefferson County, 5 miles west of Beaumont, the county seat, and 80 miles east of Houston. With regard to near-by oil fields it is 6 miles northwest of Spindletop; 2 miles south of West Beaumont; 13 miles northeast of Fannett; 14 miles east of Nome; 28 miles northeast of Anahuac; and 15 miles southeast of Sour Lake. The Southern Pacific Railroad is located one

[1] Read by title before the Association at Oklahoma City, March 24, 1939. Manuscript received, June 17, 1939.

[2] Humble Oil and Refining Company.

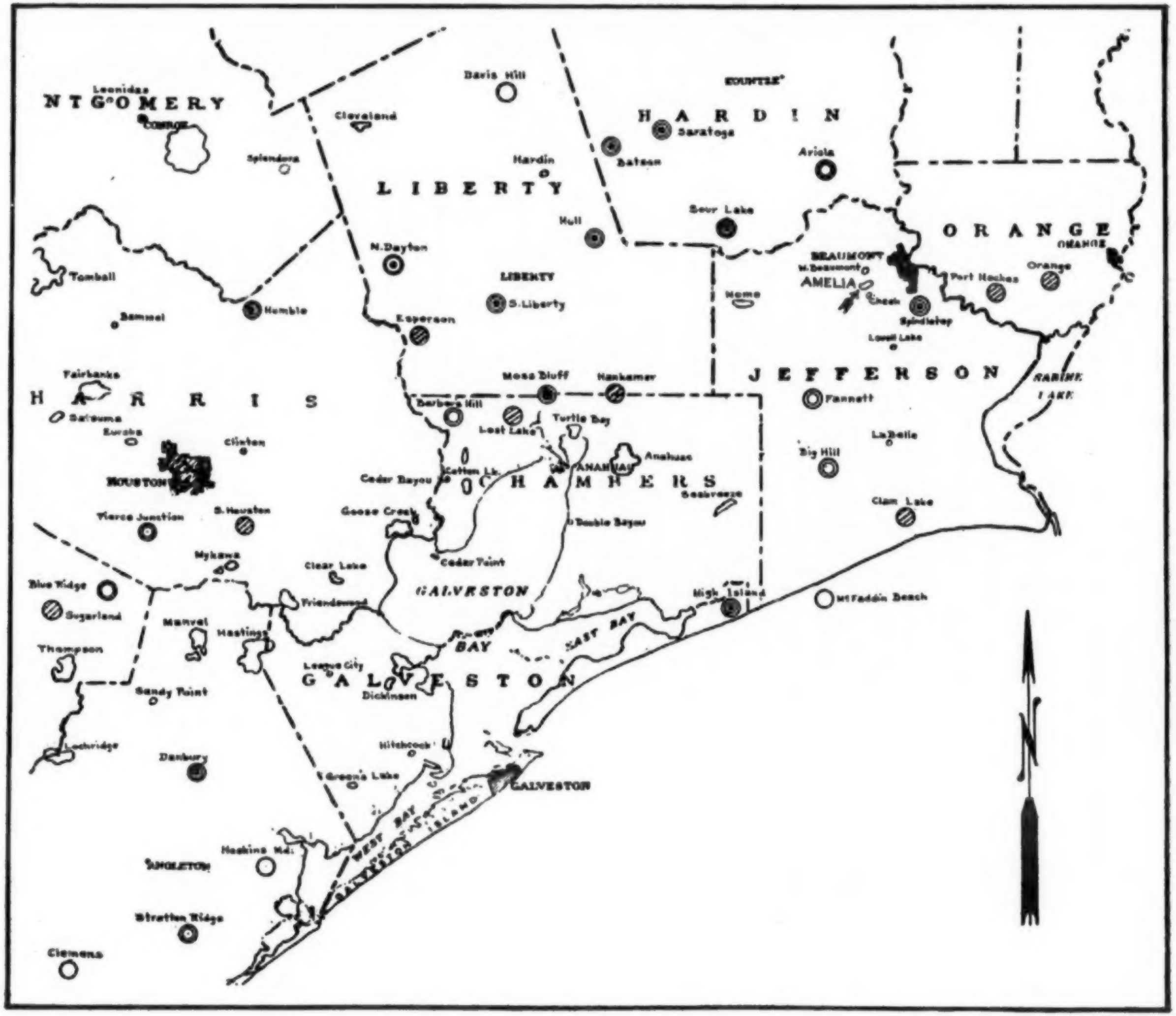

FIG. 1.—Regional map showing location of Amelia.

mile north of the field and the paved U. S. Highway 90 passes 500 feet north of the northeast end of the field.

INTRODUCTION

The development of Amelia and its attendant problems has aroused considerable interest from both geological and engineering standpoints. To the geologist concerned with areas where faulting is predominant, such as the Balcones fault zone and central Texas, the big fault would be the chief point of interest; to the Gulf Coast geologist, in whose province it lies, the domal characteristics of the field would be outstanding. However, the factors controlling accumulation prove to be a combination of both without placing any more emphasis on one than on the other.

Amelia is one of the first examples of the rather paradoxical situation where accumulation of oil is limited to the downthrown side of a fault plane rather than to the upthrown side. The fact that this type of structure occurs within a region where more orthodox salt domes, of both piercement and non-piercement types, are common, is also exceptional. A contrast results when the deeply buried, peculiar structure of Amelia is compared with the shallow, prolific, piercement-type salt dome of neighboring Spindletop. The fact that Amelia occupies the central position in a regional "high" supporting two other oil fields is also significant. Several exceptional examples of sedimentation have been revealed which should be of interest to the stratigrapher.

From the engineering standpoint with regard to completion of producing wells Amelia offered many difficulties, most of which, however, have been solved successfully and the solution has to a considerable extent affected completion methods throughout the Gulf Coast wherever similar conditions are found.

The field also offered many difficulties in land and lease work because the Amelia townsite, which is subdivided into many small lots, was pooled into 10-acre drilling units since this plan was considered to insure an ultimate recovery greater than would be expected from denser drilling and was, therefore, in accord with the principles of conservation.

HISTORY

The site of the Amelia oil field was, for many years, considered as having little significance as a possible oil field although the town of Beaumont, only 5 miles east, has long basked in the reflected glory of the great Spindletop, one of the most extraordinary and prolific oil fields in the world and one which stirred the then small oil world to its depths when it was discovered in 1901. Its discovery marked the

FIG. 1.—Regional map showing location of Amelia.

beginning of a coastwide search for domes on which to do further drilling but Amelia was passed by since no beckoning mound rose on the surface to challenge and invite the conquest of the drill.

Little did Beaumont realize that another oil field lay at its very doorstep awaiting the time when the development of science would disclose the presence of favorable structural conditions without the aid of surface indications. However, there were those who believed in the area's possibilities even though their basis for such belief must have been lacking in concrete foundation. It is said that the late Frank Yount, of the old Yount Lee Company, believed that some day there would be an oil field in the vicinity of Amelia and probably this belief of his had much to do with fostering the same idea in the minds of many others in the locality. The area now comprising the Amelia oil field was first recommended to the Humble Oil and Refining Company for lease by Ben Palmo and W. D. Blackburn, geologists for that company, in May, 1925, due to the presence of sulphur water in shallow wells.

It was not until after the introduction and development of the seismograph and other geophysical instruments that the area became interesting to oil companies. The Humble Oil and Refining Company, because of favorable geophysical information, blocked several thousand acres surrounding the Amelia townsite, and late in October, 1935, moved in a drilling rig on the R. C. Miller No. 1. This location later proved to be only one mile west of the western edge of production. It was drilled to 6,470 feet and encountered the top of the Frio, in which formation production had been expected, at 6,259 feet. This sand was found to contain salt water with no trace of oil and since no other showings had been found the well was abandoned, November 25, 1935.

The drilling rig was then moved 2 miles southeast to the Effie Willerton No. 1, which later proved to be only 3,300 feet south of production. This well, toward the expense of which the Magnolia Petroleum Company also contributed, was drilled to 6,925 feet after encountering salt-water-bearing Frio sand at 6,375 feet. It also found a salt-water sand at 6,883 feet which later proved to be the producing sand for the field; however, in this case it was 98 feet below the field salt-water level.

Still not entirely discouraged, the Humble decided to make another test and the rig was moved to the Mary Langham No. 1, 12,000 feet northeast of the Willerton No. 1, and 12,750 feet east of the Miller No. 1. The drilling of this location resulted in the discovery of the Amelia oil field although it was later found to be on the extreme

east edge of production. Further drilling showed that the field lay almost within the boundaries of the triangle formed by the two dry wildcats and the discovery well.

The Mary Langham No. 1 topped the Frio formation at 6,350 feet where salt water was again found. It was feared that this test would also be a failure since the top of the Frio was non-productive. The hole was carried down to 6,750 feet at which depth abandonment was considered, but after some discussion it was decided to drill deeper, whereupon, after drilling 15 additional feet, oil sand was encountered at 6,765 feet. This sand was a new producing sand for the Gulf Coast region and was named the Langham sand in order to distinguish it from the other Frio sands. The well was drilled to 6,791 feet at which depth a drill stem test was made, recovering 4,000 feet of pipe-line oil with a trace of brackish water. The hole was deepened to 6,903 feet in order to learn something of the sand section but all of this additional hole was salt-water-bearing. The hole was then plugged back to 6,777 feet, 7-inch casing set, and the well completed, February 12, 1936, producing 475 barrels of 29.2° gravity pipe-line oil per day through one ¼-inch positive choke, with gas-oil ratio of 290 cubic feet per barrel, tubing pressure of 675 pounds per square inch, and casing pressure of 1,000 pounds per square inch.

The successful completion of a producing well in this new sand, 415 feet below the top of the Frio, caused a return of thought to the original wildcat, Miller No. 1. The top of the Frio in that well was at 6,259 feet as against 6,350 feet for the discovery well, or 91 feet higher structurally. This fact indicated that Miller No. 1 had not been drilled deep enough to penetrate the Langham sand which should be found high and possibly productive. Accordingly, a new location, R. C. Miller No. 2, was staked and drilled within a short distance of the original wildcat. The top of the Frio in the new well was found at 6,208 feet and the Langham sand at 6,587 feet, 178 feet higher than in the discovery well, but both sands contained only salt water. This peculiarity offered rather conclusive proof that a fault existed between the two wells, the high side of which apparently was dry and the low side productive. The Miller No. 2 was drilled to 7,882 feet and abandoned while still in the Frio formation.

Another wildcat, the J. E. Broussard No. B-1, 3,000 feet east of the Langham No. 1, was drilled at the same time as the Miller No. 2. It was carried down to 8,261 feet and abandoned after encountering the Langham sand at 6,885 feet, 100 feet below the field salt-water level. The Humble then confined development to the drilling of oil wells without further wildcatting.

Glenn H. McCarthy, immediately after the completion of the Langham No. 1, drilled the Bessie M. Longe No. 1, 12,000 feet north and slightly west of the discovery well. This well was carried to a total depth of 6,820 feet and was found to be 250 feet higher on the top of the Frio than the Langham No. 1. It was plugged back, after failing to find oil production, and was completed as a gas well, producing from 5,835–5,855 feet, from a sand in the *Marginulina* zone. Subsequent development of this area, however, proved oil reservoirs at the base of the Miocene and the top of the Frio formation.

The area around McCarthy's well immediately appeared to be geologically different from the Amelia field, although, for a time, it was considered as part of the field. Subsequent drilling in the area between Amelia and McCarthy's well by The Texas Company, the Normandie Oil Corporation, and Glenn H. McCarthy, proved the upper area to be an oil field entirely different from Amelia.

For about 10 months after the discovery of oil, the whole area was known as West Beaumont and it was not until a hearing was held before the Texas Railroad Commission in December, 1936, that the two areas were officially divided and classified as separate oil fields. The area on the north, around McCarthy's well, was named the West Beaumont oil field, and the area at the south, with which this paper deals, was named the Amelia oil field.

TOPOGRAPHY AND GENERAL SURFACE CONDITIONS

The area comprising the Amelia oil field consists of flat, fertile, prairie land, most of which is used for pasturing livestock and with the remainder forming the south part of the Amelia townsite. There is a strip of wooded territory of pine and a mixture of hardwood at the north end of the field which made it necessary to clear one location for drilling.

There is a gentle slope of 2 or 3 feet per mile in a southeasterly direction and all drainage naturally follows in that direction. Ground elevations on the extreme west side of the field average 26 feet above sea-level, the central part of the field averages 24 feet, and the extreme east side has an average elevation of 22 feet. For the purpose of general discussion in this paper derrick-floor elevations have been given an average of 35 feet above sea-level.

The whole of the area was originally under rice cultivation and was considered very good rice land. Almost all of the old settlers of the region are retired rice farmers. At one time the western part of the field was a large fig orchard but a severe freeze which occurred about 15 years ago eliminated that culture. However, the old fig area,

now the Tyrrell-Combest Realty Company lease, is still called "Fig Acres." An irrigation canal, belonging to the Texas Public Service Company and dug during the time the area was used for growing rice, crosses the middle of the field and from it was taken the water necessary for drilling development.

The townsite of Amelia, lying on the Beaumont-Houston highway, occupies the northwest side of the field. This townsite is subdivided into many small lots supporting a goodly number of private homes. These homes are served by a network of good shelled streets which were a great help in transportation of drilling and production materials. These streets, a county shelled road which bisected the field, and a road which the Humble built, adequately served the needs of the entire field. The big fault, which limits production to the north, crosses the townsite diagonally, leaving the north half dry and the south half productive.

Gas for drilling during the early life of the field was obtained from a line belonging to the United Gas which crosses the north part of the field.

Fresh water for domestic purposes is obtained from wells varying from 20 to 350 feet in depth.

The mean annual rainfall and temperature are approximately 48 inches and 69° F., respectively.

STRATIGRAPHY

SURFACE FORMATIONS

The surface is covered by the normal outcrop of the Beaumont clay and is very close to the type locality of this formation. The outcrop is, in general, dark, weathered, gray clay supporting a broad treeless plain interrupted by a few wooded areas. Practically all of the drainage ditches in this region show this outcrop to good advantage.

SUBSURFACE FORMATION

Beaumont clay (*Pleistocene*).—From the surface to 200 feet the formation is dark gray, slightly sandy clay with several well defined fresh-water-sand members. These water-sand members are fairly continuous as shown from core drilling information. There is some evidence of structural uplift in the Beaumont clay, as it is possible to map a fault from the difference in positions of the fresh-water sands.

Lissie-Citronelle group undifferentiated (*Pleistocene and Pliocene*).—From 200 feet down to 1,850 feet, the formations are tentatively classified as Lissie-Citronelle with no attempt made to distinguish between the two because of their lithologic similarity and the lack

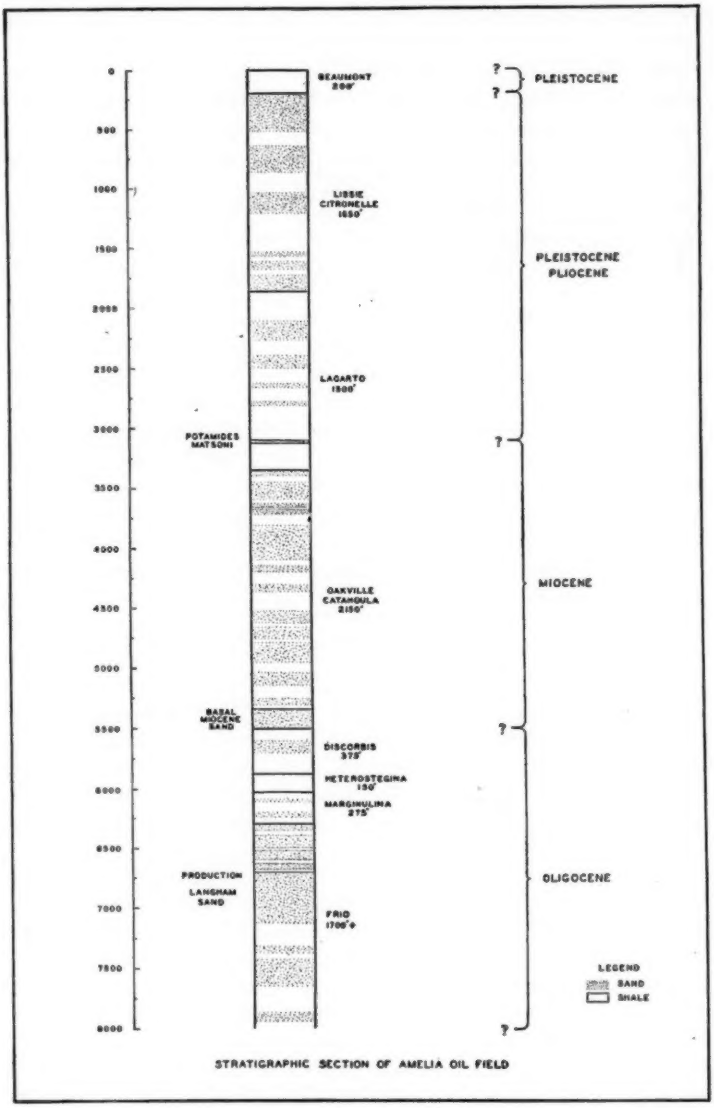

FIG. 2.—Generalized stratigraphic section encountered in Amelia oil field. Formation ages are tentatively assigned.

of any definite information. This zone consists of several thick, loosely consolidated sand bodies separated by breaks of sandy clay and with a few zones of what is probably marine clay. The sand bodies comprise about 60 per cent of the section and grade in content from fresh water at the top of the zone to salt water at the bottom. The formation undoubtedly contains several loose gravel beds as evidenced by the fact that drilling mud returns were often lost.

Lagarto clay (*Pliocene and Miocene*).—The Lagarto ranges from 1,850 feet to about 3,350 feet and is predominantly yellowish to reddish brown clay streaked with a few sand bodies. The formation, which is about 1,500 feet thick at this locality, is 77 per cent clay and shale and about 23 per cent sand. These clays offer sticky resistance to drilling but make good drilling mud and can be penetrated very rapidly. Several well developed oyster-shell beds occur throughout the section and near the base of the formation at about 3,100 feet is found the gastropod, *Potamides matsoni*, marking the first occurrence of the Miocene.

Oakville-Catahoula undifferentiated (*Miocene*).—These two formations together are about 2,150 feet thick and occur from 3,350 to 5,500 feet. No attempt is made to separate them because of lack of definite data and because of their apparent lithologic similarity. They consist of alternating layers of soft, loose, porous sand bodies and soft, brownish red, green, and greenish gray mottled clays and shales. The percentage of sand is relatively much higher in the upper part of the section which includes the Oakville; however, upon consideration of the entire zone the total thicknesses of shale and sand are found to be about equal. At the base of the formation is the 250-foot sand body known as the basal Miocene sand. The shale beds of the formation contain a few foraminifera, oyster-shell beds are fairly numerous throughout the section, and some lignite is encountered in the lower part of the zone.

Discorbis zone (*Oligocene*).—This zone, averaging 375 feet in thickness and occurring from 5,500 to 5,875 feet, is characterized by the first occurrence of true index fossils in the stratigraphic column of the Gulf Coast. Unlike the *Discorbis* zones of most Gulf Coast fields this section is very sandy in its upper half, a fact which seriously impaired its value as a key horizon at Amelia. These upper *Discorbis* sand bodies made it very difficult to distinguish the diagnostic fossils at the point of their first occurrence. Perhaps if cored sections had been taken in all wells the foraminiferal zones could have been distinguished successfully; however, bit cuttings were all the paleontologist had to rely on and all these cuttings are poor when sandy formations

are drilled. Lying in continuous streaks through the upper sands and below the base of the sands is the true *Discorbis* shale. This formation is firm, brittle, dark greenish gray, fossiliferous shale. The diagnostic fossils, foraminifera, are *Discorbis nomada*, *Siphonina advena*, *Eponides ellisori*, and *Nonion scaphum*. Many other forms are also numerous but they are of less importance.

Heterostegina zone (*Oligocene*).—This zone, 150 feet thick, occurs between 5,875 and 6,025 feet and is identified by the first occurrence of the large index foraminifer, *Heterostegina texana* (Gravell and Hanna). This zone consists entirely of shale very similar to the *Discorbis* shale previously described, which makes it impossible to distinguish the difference between the two zones in hand specimens. No sands are present within the limits of this zone and the dense limestone bed so characteristic of the *Heterostegina* zone in other localities is also absent. Limestone nodules occur here and there but no trace of the "hard lime" can be found. This absence of the limestone is difficult to explain inasmuch as the zone at Lovell Lake, 5 miles downdip, has more than 150 feet of broken limestone represented in the zone. Small crystals of pyrite and nodules of marcasite are numerous, many appearing in washed-sample residues. The foraminiferal fauna is represented by all of the *Discorbis* zone fossils and many new, more robust forms, chief among which is the diagnostic *Heterostegina texana* (Gravell and Hanna).

Marginulina zone (*Oligocene*).—This zone, 275 feet thick, occurs between 6,025 and 6,300 feet and is predominantly dark, grayish green, brittle shale of the same general lithologic character as the shales of the *Discorbis* and *Heterostegina* zones. This section contains the same fossils represented in the two zones above plus many new forms, chief among which is the foraminifer, *Marginulina mexicana* var. *vaginata* (Garrett and Ellis), the diagnostic fossil of the zone. The continuity of the zone is broken by two distinct sand bodies which are called the *Marginulina* sands and are productive in some fields. The upper sand, 10 feet thick, occurs from a few feet to 100 feet below the top of the zone. This upper sand, however, is not continuous and dies out completely in a southwest direction. The other, lower sand, 50 feet thick, 175 feet below the top of the zone, is poorly developed in the northeast and central parts of the field but becomes a well developed, clean sand body as it dips off in a southwest direction, the same direction in which the upper sand lenses out.

Frio formation (*Oligocene*).—This formation, at least 1,800 feet thick, occurs from 6,300 feet down to the deepest yet penetrated at Amelia. Its probable thickness should be about 2,200 feet. The for-

mation is composed of numerous bodies of soft, clean, porous, gray sands which vary in texture from fine to coarse. There are nine distinct sand members in the formation, varying from 25 to 475 feet in thickness. In addition to these large bodies numerous thin sand streaks occur. All of the major sand bodies except the top member are fairly continuous and regular across the entire field. The top member, 50 feet thick, is thinner on the flanks of the reservoir and appears to be thinning or dying out in the downdip direction. The percentage of sand for the entire formation is about 55 per cent; however, for the first 1,000 feet of the formation the sand bodies comprise more than 75 per cent of the total.

The Langham sand, which is the producing member, is the sixth major sand of the series and is the thickest and best developed sand body of the group. It ranges in thickness from 425 feet on top of the structure to 475 feet on the flanks and occurs from 6,700 to 7,125 feet approximately. All of the sands except the thin top section of the Langham sand are salt-water-bearing and therefore non-productive.

The sand bodies are separated by beds of dark, grayish black, brittle and sandy shales much like the Oligocene shales above. These shale beds are all more or less fossiliferous but no diagnostic fossils of any real value occur.

One important characteristic of all of the sands is the fact that they contain, or are partly composed of, some volcanic ash. Where the ash is more predominant the sands are finer, tighter, and very silty in appearance.

SUBSURFACE STRUCTURE

The subsurface structure of the Amelia field is a flat, egg-shaped, elongate dome or anticline adjacent to a big fault. The long axis of the structure trends northeast and southwest and the field is fairly symmetrical although the short axis of the dome is somewhat closer to the southwest end of the producing area. The amount of structural uplift on the Langham sand is about 300 feet which is approximately double the total structural closure.

Uplift of formations younger than the Frio is probably present to some extent but with the data at hand it is impossible to make an accurate estimate of the true amount. Sedimentation studies made from wells a mile updip from the field vary so much from similar studies made a mile downdip from the field that it is difficult to arrive at a satisfactory conclusion regarding the original position of the different formations.

The oil and gas closure based on the Langham sand horizon equals

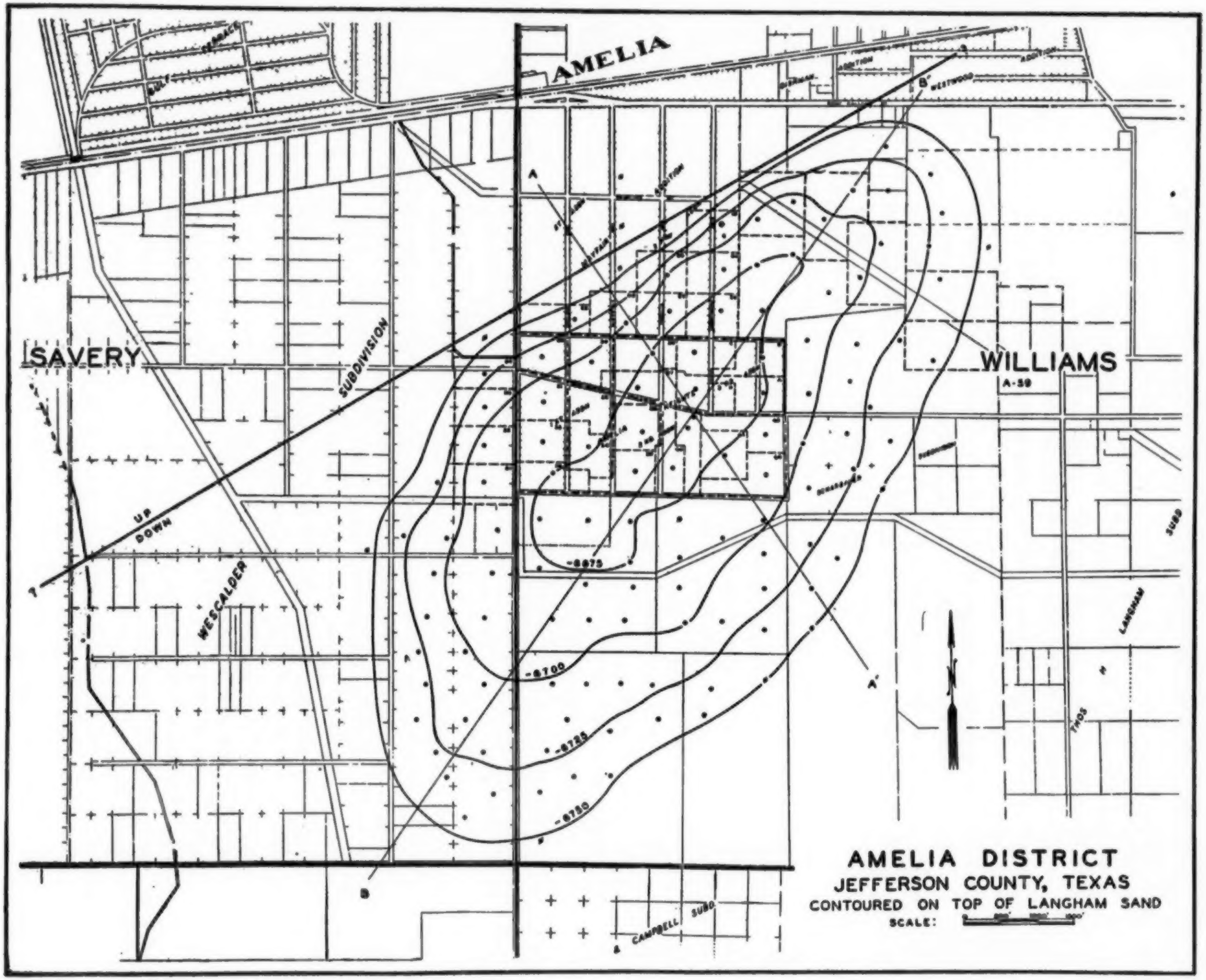

FIG. 3.—Geologic structure map, Amelia oil field. Contours based on top of Langham sand, subsea depths in feet.

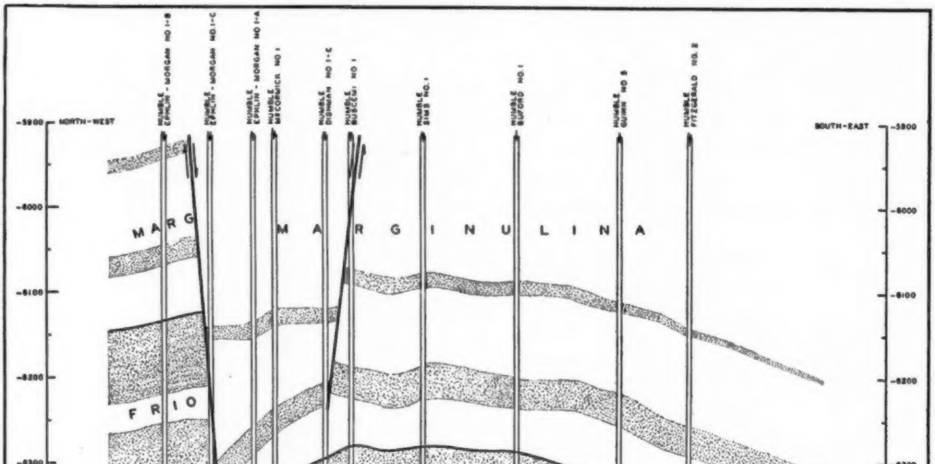

FIG. 4.—Geologic section through Amelia field from northwest to southeast along line *AA′* in Figure 3.

FIG. 3.—Geologic structure map, Amelia oil field. Contours based on top of Langham sand, subsea depths in feet.

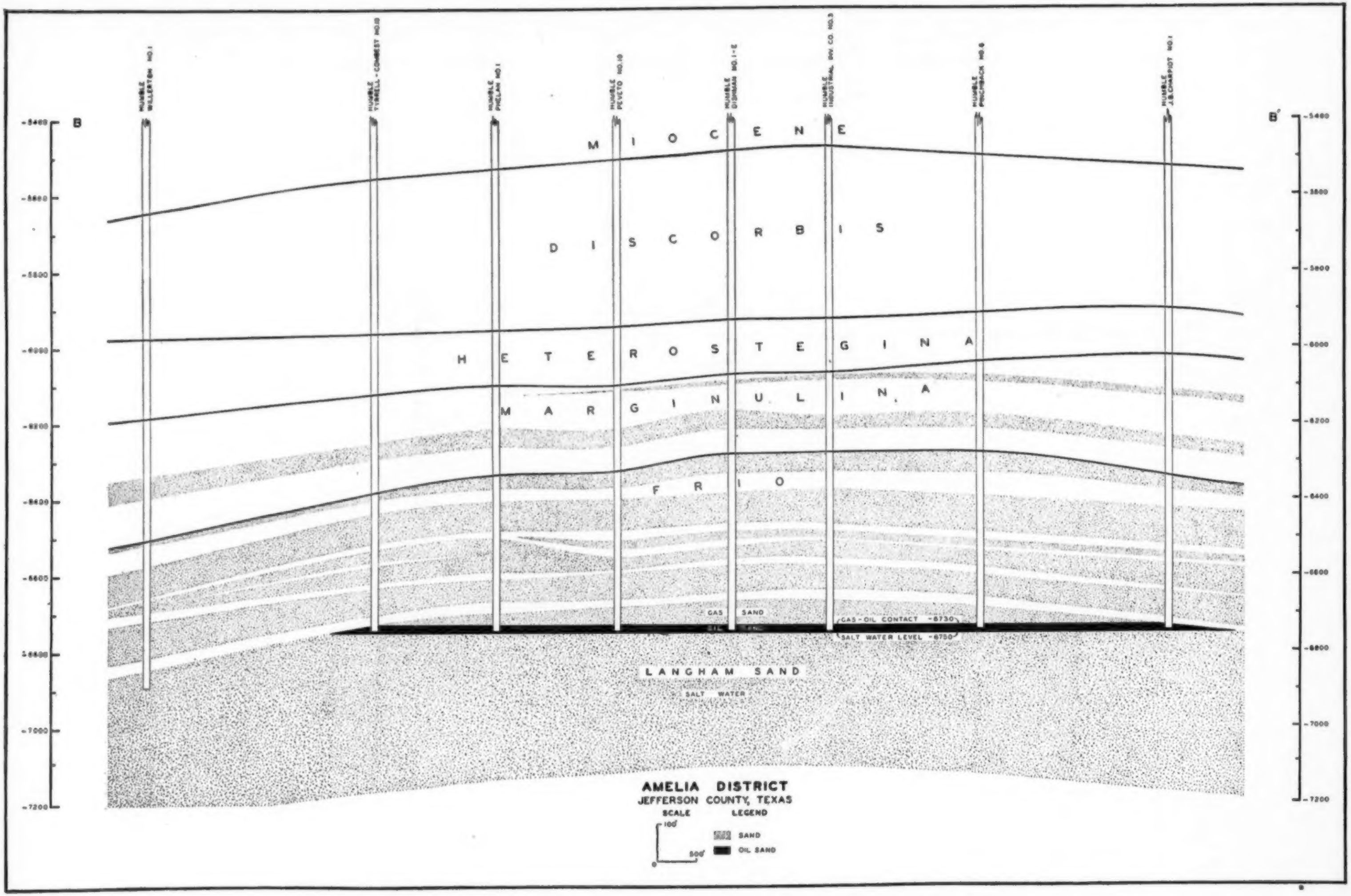

FIG. 5.—Geologic section through Amelia field from southwest to northeast along line *BB'* in Figure 3.

91 feet and the total structural closure amounts to not more than 150 feet. The highest well drilled on the low side of the fault and in the productive area is the Humble Oil and Refining Company's LeGrange No. 1, Amelia townsite, which found the top of the Langham sand at 6,694 feet.

Thinning of formations over the dome is perceptible to a small degree in the recognizable formations of the Oligocene. The interval from the top of the Frio to the Langham sand varies from 390 feet at the peak of the structure to 415 feet at the edge of production and to 440 feet ½ mile downdip from production.

The Amelia reservoir extends 10,650 feet northeast and southwest with its long axis at an angle of about 20° to the big fault. The short axis of the field from northwest to southeast is almost exactly one mile in length.

The structure offers the somewhat paradoxical situation of an accumulation of oil lying on the downthrown side of the big fault rather than on the upthrown side and is one of the first examples of this exceptional occurrence in the Gulf Coast. Five wells have been drilled on the upthrown side of the fault and as yet no definite evidence of structural closure has been found on that side. However, there is slight reverse dip between two adjacent dry holes, Haltom, Ephlin, and Morgan's C No. 1 and B No. 1.

FAULTS

Unlike most Gulf Coast oil fields, Amelia is almost free from faulting in the producing area. Only one small fault has been found inside the producing area and it dies out before it reaches the top of the Frio. This fault seems to have no bearing or effect on the producing formation. It is a complement to the big fault and the wedge of sediments between the two appears to be a small graben or downthrown block. The direction of this fault seems to be nearly parallel with the main fault, the vertical displacement on the *Marginulina* sand is 50 feet, and the hade of the fault plane has not been determined. It is of the normal type with the shear plane dipping toward the downthrown side.

The big fault trends northeast and southwest and is of the normal type with a dip of 45°. This dip has been accurately computed from the difference in the points where it crossed two adjacent wells, Haltom, Ephlin, and Morgan's B No. 1 and C No. 1. Both of these wells were dry because they crossed the fault and encountered the high side where all of the sand is salt-water-bearing. As nearly as can be determined the fault has a vertical displacement or throw of 180

feet as evidenced by the fact that this is the actual amount of section lost by Haltom, Ephlin, and Morgan's C No. 1 which cut the fault in the *Marginulina* zone at 6,250 feet.

Although this fault may be said to be the northern limit of production the oil productive area does not actually reach the fault plane. The lowest productive contour, −6,750 feet, parallels the plane at a distance of 200–500 feet southeast from the shear zone. The beds then dip very steeply from this edge of production toward the fault zone and as a consequence three dry holes have been drilled in this narrow area.

No definite information is available about the length of this fault; however, it is thought to extend several miles in either direction and may reach the surface, as a small fault can be mapped in the Beaumont clay at approximately the position where this fault should cut the surface. This assumption would naturally make the fault younger than the Pleistocene Beaumont clay.

ORIGIN OF UPLIFT AND ACCUMULATION OF OIL

Nothing very definite can be concluded regarding the origin and history of the uplift because very little uplift can actually be defined. There is a possibility that the uplift may have been caused by the upward movement of a very deeply buried salt mass, beginning probably in pre-Tertiary time. Subsequent sediments could have been deposited over the whole of the old uplift with the growing salt mass imparting to them the general shape of the rising uplift. This theory places the fault as a secondary feature, occurring either while uplift was actually taking place, or long after some uplift was present, and caused by tension across the top of the fold. The oil accumulation could have formed at the original crest of the structure and then, when the faulting occurred, the high part of the uplift containing the oil and gas could have dropped to occupy its present position on the downthrown side. Since there is a shale seal between the reservoir and the fault plane and the sand also dips below its water level before it reaches the fault, the oil could not have escaped to the high side. Evidence supporting the secondary origin of this fault is that the fault can be regarded as being very youthful since it could possibly be the same fault previously mentioned as cutting the Beaumont clay, in which case it would be as young as, or younger than, that formation.

The fault, under this theory, can be considered as neither arresting migration of the oil nor aiding in its accumulation. It is simply a secondary feature and differs from faults in some of the other Gulf

Coast fields only in the fact that production does not exist on both the high and low sides. If the fault is disregarded entirely, Amelia seems to be a simple, orthodox, deeply buried, domal field.

Another plausible theory is that the whole area for several miles around became regionally high due to the many and varied tectonic movements of that part of the Gulf Coastal Plain. The tectonic history of this area has been very full and varied when one considers the number and different kinds of salt domes and other structures existing within a radius of a few miles; namely, Spindletop, Fannett, Hull, Orange, Big Hill, High Island, Nome, Anahuac, Hankamer, Lovell Lake, West Beaumont, and several others. Later downwarping of the Gulf Coastal Plain, which in all probability could be proved by a study of existing unconformable relations, could be responsible for the faulting. Still later lateral movements of a very gentle nature could have slightly folded the sediments against the fault plane, thus forming the reservoir. This theory is plausible since the long axis of the field is almost parallel with the fault plane and the short axis is almost perpendicular to it, showing undoubtedly that such folding has taken place to some extent. The beds are arched more and the dip becomes much steeper in the area closest to the fault zone which naturally would have been the place where folding and buckling first affected them.

Under this latter theory the oil could have migrated into the small reservoir from the southeast downdip direction. It is possible that oil is still migrating in since equalization of the water level due to difference in fluid densities has not been reached and sands stained with oil persist as much as 15 feet below the salt-water level of the reservoir. This latter fact, of course, is also common to almost all of the more domelike structures of the Gulf Coast. Any oil which traveled across the fault below the shale seal could not have remained long on the high side because apparently there is no structural closure present to act as a trap for the less dense fluid and gas. Thus the oil would have had no alternative but to migrate farther updip until it did find a reservoir in which to accumulate and form another oil field. This possibility may explain the accumulation of oil at West Beaumont, 2 miles updip on the north.

In conclusion, it may be said that structural folding, interpreted in the strict sense, which has heretofore occupied a position of minor importance in Gulf Coast oil-field geology, could be termed as responsible for the formation of the Amelia reservoir although the original structural movement may be due to other causes. However, since the field occurs within an area dominated by strictly orthodox

salt domes of both piercement and non-piercement types, the writer feels that Amelia probably has its own salt mass underneath and should be considered as simply a deep-seated dome with extraordinary faulting complications. A non-piercement type dome is herein defined simply as one which has a salt core, probably very similar to that of a piercement-type dome, at much greater depth, in nearly all cases never reached by the drill.

PRODUCING SAND

The only producing formation at Amelia is the Langham sand, so named because of its discovery as a producing sand in the Mary Langham No. 1. It belongs to the Frio formation, is the sixth major sand body of that group and is found between 390 and 415 feet below the top of the formation. It lies continuously and regularly over the entire structure and is 425 feet thick at its highest point and 475 feet in thickness at the lowest known point.

The sand body is remarkably clean and uniform in lithologic character. The porosity average is 30 per cent and the permeability 900 millidarcies parallel with the bedding planes and 700 millidarcies perpendicular to bedding. The sand is ordinarily very soft and loosely consolidated and the texture of the grains varies from medium to coarse with very little fine material present. A few lenses and islands of shale and sandstone, varying in thickness, occur throughout the sand body but seem to be very irregular and inconsistent. Many wells logged pure sand for the entire section penetrated. There is one rather persistent break in the sand body although it has peculiar variations. It begins as a very shelly, porous sand streak, 2–10 feet in thickness, occurring from 25 to 35 feet below the top of the sand, and extends from the northeast side of the field to the lower southwest-central part of the field where it suddenly changes into a shale body occupying the same stratigraphic position. This transition is effected completely in the short 660-foot distance between offset wells. The shale body is dense lignitic shale, varying in thickness from 2 to 17 feet. In some places pure lignite is found and in others the break is all shale.

These shale islands, sandstone lenses, and big shale breaks served to good advantage, however, when they happened to occur between the gas and oil sand. In several places, on the other hand, the big shale break almost ruined the wells by occupying most of the oil zone. One well found only 21 inches of oil sand between the shale and salt-water level but was completed as a fair producer.

The Langham sand produces oil between the limits of −6,730 feet and −6,750 feet in a proved area of 1,180 acres. It is separated

from the considerable thickness of salt-water-bearing sand above by a brittle shale break averaging 22 feet in thickness.

RESERVOIR CONDITIONS

GAS-OIL LEVELS

The gas-oil contact in the Langham sand reservoir is a remarkably uniform plane throughout the field and is found at −6,730 feet. The contact will not vary more than 4 feet from this depth in any well except those located on the extreme northwest edge of production. In that area there is no gas-oil contact and it is impossible to complete wells with low gas-oil ratios. Although the top of the sand is encountered in these wells below the normal gas-oil contact and within the limits of the oil zone, it contains free gas with oil down to the salt-water level. There is no permeability or porosity difference noticeable in the sands of this gassy area in comparison with the rest of the field. The reason for the gas occupying this abnormal position could be explained by pointing out that the reservoir has probably not reached its absolute equalization stage.

The ordinary gas-oil contact is a sharp line easily recognized by the naked eye. The clean, gray gas sand changes to well stained oil sand within the distance of a foot or two. This point, of course, is not the point where wells can be completed with a low ratio. Free gas is ordinarily associated with the oil for several feet below the contact even though the sand appears well saturated with oil. There are some zones of sand in the Langham sand body which are brown and look exactly like the oil sand even though containing no oil. Where the gas-oil contact occurs in one of these zones, it is difficult to recognize the exact contact without using ether for definite determination of the presence of oil.

OIL ZONE

The oil zone, which lies between the gas-oil contact and the salt-water level, is 20 feet thick and is found between −6,730 and −6,750 feet. This thickness is much less than that of the average Gulf Coast field and for that reason the ultimate production from Amelia will be comparatively small. From a point about 8 feet below the top of the zone through the remaining 12 feet to the salt-water level the sand produces with a low gas-oil ratio. However, in order to hold back free gas production and stay as far above salt water as possible, it was necessary to restrict the production of each well to a 3-foot interval usually located as close to the middle of the oil zone as possible. The sand is well saturated with oil and compares favorably in permeability and porosity with the sands of other Gulf Coast fields. Due to its

depth restrictions the oil zone may be found in the top of the Langham sand in edge wells and as much as 70 feet below the top of the sand in the high part of the field. In most places the entire zone is clean sand but here and there are breaks previously described, included within its limits, thereby reducing the actual amount of oil sand.

OIL-SALT-WATER LEVEL

The oil-salt-water level is encountered at an average depth of $-6,750$ feet and similar to the gas-oil contact it is subject to slight variations in either direction. In the west and northwest part of the field, and including the area where there is no gas-oil contact, the salt-water level seems to be 3 or 4 feet higher than in the rest of the field. The exact level is difficult to distinguish by examination of core samples because of the fact that the upper 10–15 feet of the salt-water sand everywhere appears fairly well saturated with oil as well as salt water. This part of the sand, however, when tested yields nothing but salt water although some oil is actually present. Accurate data on the salt-water level have been obtained from relatively few wells because most of the wells were bottomed as high above the water table as possible.

GAS CAP

The oil from the Langham sand becomes gas saturated at a pressure of 2,865 pounds per square inch, 164°F., and since it was associated with additional gas in the reservoir, which could therefore not become dissolved in the oil, it allowed the free gas, which has less density, to rise to the top of the reservoir and become a gas cap. This free-gas zone attains a maximum thickness of 71 feet at the crest of the structure and from that point thins down to nothing at the $-6,730$ structural contour or very close to the edge of production. The average thickness of the zone is approximately 50 feet and the average porosity is 30 per cent. The total area covered by the gas cap is approximately 1,000 acres, which is 85 per cent of the total productive area. The only part of the field where free gas does not exist is the narrow peripheral area of the reservoir where the top of the sand is below the gas-oil contact. On the west and northwest edges the free gas extends to the salt-water level.

Fifty feet of gas sand thickness multiplied by 1,000 productive acres equals 50,000 acre-feet of gas sand, and since one acre-foot at atmospheric pressure, 60°F., contains about 2,500,000 cubic feet of gas, the original volume of free gas was probably close to 125 billion cubic feet.

Under the present proration rules the gas cap is being preserved and therefore acts as a stabilizer for pressures within the reservoir. As the oil is slowly withdrawn the level plane of the base of the gas cap will eventually come into contact with the rising salt-water level, thus subjecting the oil zone to a vice-like squeeze which should result in longer well-flowing life and a higher percentage of oil recovery.

RESERVOIR PRESSURES

Bottom-hole-pressure studies have been made since the beginning of field exploitation in order to keep an accurate record on the behavior of the reservoir. The common method of taking the measurements is to shut in the wells to be tested 24 hours before the pressure bomb is run in order to allow the pressures to build up to maximum. Experiments and tests have been made with the wells both shut in and flowing in order to study the pressure drops for different withdrawal rates and to compute productivity factors.

The original reservoir pressure, measured in the Mary Langham No. 1, the discovery well, was 3,150 pounds per square inch at −6,730 feet. Subsequent pressures measured since that date have fluctuated, due to unequalization of the reservoir. After nearly 3 years of flowing life and 77,000 barrels production, the pressure of this particular well has dropped to 3,000 pounds, a decrease of 150 pounds, which is only 23 pounds lower than the present average for the entire field.

The first data recorded on pressure drop in pounds per million barrels of oil produced were computed on May 1, 1937, when the cumulative production was only 349,100 barrels and the daily withdrawal rate was 1,255 barrels from 25 wells. The average reservoir pressure at this date was 3,089 pounds and the drop in pressure per million barrels produced was 174.5 pounds. This sharp decline in pressures in the early life of a reservoir is a natural phenomenon as shown by experience with other Gulf Coast reservoirs.

The next general survey was made in October, 1937, when the cumulative production was 1,006,400 barrels with a daily production of 4,000 barrels from 100 wells. The average pressure for the reservoir at this date was 3,051 pounds and the pressure drop per million barrels produced was 98.5 pounds, or 44 per cent less drop than that shown by the preceding survey.

A general survey, made in February, 1938, when the cumulative production had reached 1,500,000 barrels with a daily withdrawal rate of 4,130 barrels from 110 wells, showed an average pressure of 3,044 pounds per square inch which is only 7 pounds less than the average of the survey taken three months previously. The pressure

drop per million barrels produced was 71.7 pounds or 27 per cent less than that shown by the previous survey. Early equalization of pressures and general stabilization of the reservoir forces is directly indicated by the results of this survey.

The last general survey, taken in September, 1938, eight months after the foregoing survey, when the cumulative production had reached 2,248,000 barrels, showed still greater tendencies toward eventual stabilization. The daily withdrawal rate at the time of this survey was 3,640 barrels from 114 wells; the average pressure was 3,023 pounds per square inch, or 19 pounds less than it had been eight months previously; and the pressure loss per million barrels produced was 56.4 pounds, or 21 per cent less than that of the February survey.

These data and results tend to prove that bottom-hole pressures are subject to fluctuation and rapid decline during the early development of a field when the number of wells is constantly increasing and the withdrawal rates are fluctuating. However, some areas of the field are already showing promise of future equalization. Since the reservoir sand at Amelia is very uniform and permeable the pressure equalization and adjustment point should be reached in a minimum of time now that development is completed and withdrawal rates are fairly constant.

The field is subject to a water drive which probably is as nearly perfect as possible. From the extreme edges of production across the entire producing area the oil zone is underlain by, and in direct contact with, salt-water sand varying in thickness from 334 to 475 feet. This sand can be traced to its outcrop position and therefore should have the benefit of a full hydrostatic head.

The productivity factor, as measured in the Langham No. 1, an edge well, was 1.781 barrels of oil per day per pound drop in bottom-hole pressure. The specific productivity factor for the same well was 0.3562 barrels per day per pound drop in pressure per foot of sand screened.

PRORATION

The Amelia oil field has been drilled to a density of one well to each 10 acres and production has been held under strict proration since the field was first discovered. The maximum daily allowable of the discovery well was only 150 barrels and this allowable was for a relatively short time. As the number of producing wells increased the well allowables all suffered general decreases.

Individual well allowables were based on a flat figure per well, disregarding the potential and acreage factors which are the decisive factors in determining allowables for the majority of the Gulf Coast

fields. Any well producing with a gas-oil ratio of less than 2,000 cubic feet of gas per barrel of oil was entitled to a full allowable. Those wells which had gas-oil ratios in excess of 2,000 cubic feet were curtailed according to their gas production in the following manner. The allowable of a normal well was multiplied by 2,000, the ratio limit, and then divided by the ratio of the well in question. The resulting figure would be the allowable of the well and would necessarily be much smaller than that of the normal well. This practice, in accordance with strict conservation, prevented a well which produced too much gas from depleting the reservoir energy any more than a normal well. Naturally this policy put a premium on low-ratio wells with resulting conservation of reservoir energy.

The present daily allowable is 40 barrels per well for all normal wells. The total daily normal allowable plus the smaller abnormal allowables equals 4,374 barrels for the entire field.

Proration in its broad sense is a life-saver for fields of the Amelia type. Had conservation measures and rules not been in effect Amelia would be a very different oil field in comparison with its present status. In all probability the high gas-oil ratio wells would not have been reworked and the valuable gas supply would have been rapidly depleted, thereby losing or decreasing the motivating force so necessary for recovering the oil. Undoubtedly, the wells would have been allowed to produce too rapidly which would have resulted in raising the originally uniform water levels in uneven levels and cones, causing the premature drowning of many wells in salt water with resultant permanent loss of much oil. In order to summarize the benefits of proration, it may be said that had Amelia been drilled and produced under the practices in vogue 20 years ago it would have been relatively unimportant in comparison with its status under modern conservation practices.

DEVELOPMENT AND PRODUCTION

During the first year of development at Amelia only 19 wells were drilled, four of which, including the preliminary wildcats, were dry and abandoned. A second drilling rig was moved into the district after completion of the discovery well, but after drilling two wells it was shipped away, leaving only one rig to operate for the first year.

Late in February, 1937, drilling operations began in earnest and for a period of 8 months eleven rigs were operated in the field. At the present time, March, 1939, drilling development regarding all known conditions is entirely finished.

To date, 132 wells have been drilled in the field, 129 by the Humble Oil and Refining Company and three by the Normandie Oil Corporation. Of these, 115 wells are producing oil, 16 are dry and abandoned, and one is a gas-distillate well permanently shut in, having been replaced by an oil well drilled on the same 10-acre unit. Of these 115 oil producers, 14 produce varying amounts of salt water, the highest individual percentage being 50 per cent; six of the salt-water producers are on the west edge of the field where the salt-water level is higher than normal, and the other eight were all completed much closer to the water level than the average well because of abnormal conditions such as shale breaks, sandstone lenses, *et cetera;* seven of the 14 water producers were originally completed producing some salt water. Eight of the 115 producers are high gas-oil-ratio wells, with consequent lower allowables, four of which are also listed among the 14 salt-water producers. To briefly summarize, 97 wells are producing under normal conditions and 18 under abnormal conditions.

The wells all flow naturally through adjustable flow-line chokes which are usually adjusted to sizes less than $\frac{1}{8}$ inch in order to regulate the flow of the well in accordance with its prorated daily allowable. When the oil wells are originally completed, they are allowed to flow for 24 hours through a $\frac{1}{4}$-inch positive-type choke in order to obtain the well-potential gauge required by the Railroad Commission of Texas. The gas accompanying the oil is metered accurately through orifice meters. The average well potential is about 650 barrels of oil in 24 hours through $\frac{1}{4}$-inch choke, gas-oil ratio of 390 cubic feet per barrel, tubing and casing pressure equalized at 1,000 pounds per square inch. The highest potential yet recorded at Amelia was 730 barrels from the T. E. Buford No. 1.

The oil produced at Amelia has a gravity averaging 29.5°A.P.I., corrected to 60°F. It is essentially a paraffine-base crude which is high in lubricating stock. The oil will liberate from solution 400–410 cubic feet of gas per barrel from 125-pound separator pressure to atmospheric pressure, 60°F. The gas-free oil occupies 0.83 barrel per barrel of original oil at 2,865 pounds and 164°F.

About the only difficulty experienced in producing the oil is that small amounts of paraffine wax are deposited on the walls of the tubing and flow lines, thus restricting normal flow. This deposit, which is due, probably, to the slow rate of production, can be flushed out by increasing the rate of flow for a short time. If the deposit is neglected, however, it often becomes necessary to drill and scrape it out. The oil from the wells which also produce salt water is flowed through a heater where it is heated up to a temperature between 100° and 125°F.

and thence through a flume into a gun-barrel tank where the water drops out by gravity action allowing the clean pipe-line oil to go out the top of the tank into storage. Occasionally some of the more stubborn emulsions are chemically treated.

The proved area of the field is 1,180 acres and the probable total area is 1,220 acres. To January 1, 1939, the field has produced 2,644,642 barrels of oil from 114 wells which is an average of 2,168 barrels per proved acre. The oldest producing well in the field, the Mary Langham No. 1, has produced 77,000 barrels and is still steadily flowing with prospects of good future production.

DRILLING METHODS AND PRACTICES

All wells were drilled by the medium-heavy types of steam-powered rotary drilling rigs and the methods practiced were in accordance with A.P.I. specifications and the field Railroad Commission regulations. The holes were kept as straight as possible and when abnormal deviation did occur immediate steps were taken to straighten the crooked hole. Straight-hole surveys were taken every 500 feet while drilling and the common practice was not to exceed 3° from the vertical.

About two-thirds of the wells completed were drilled by contract rigs and the remainder by company-owned tools. The average time for drilling and completing a normal well was 15 days; however, several wells have been drilled in 12 days. When it became necessary to rework an abnormal well, the time period varied from 20 to 66 days according to the type of work-over and the trouble encountered.

During the early stage of development, 16-inch conductor casing was set and cemented at 200 feet; $10\frac{3}{4}$-inch surface casing was set and cemented at 2,000 feet; and 7-inch oil string was set and cemented near bottom. When development began in earnest, this policy was somewhat modified: a $12\frac{1}{4}$-inch hole was drilled to 1,050 feet where a string of $9\frac{5}{8}$-inch, welded, 34-pound, seamless steel casing was set and cemented with 300 sacks of cement. After this cement had been allowed to harden for 48 hours the plug was drilled out and $8\frac{3}{4}$-inch hole was drilled to the point, usually about 6,750 feet, where it was desired to core for the sand. A $6\frac{3}{4}$-inch rathole was then drilled with a wire-line core barrel to the total depth of the hole, usually about 6,778 feet. An electrical logging survey was then made; the hole was reamed out to $8\frac{3}{4}$-inch to the total depth; and $5\frac{1}{2}$-inch outside dimension, seamless steel, 15-pound casing of the screw type was set and cemented with 300 sacks of cement at the desired casing seat. This cement was allowed to set 48–72 hours and the inside plug was

then drilled out and the open hole below the casing washed and cleaned with the same bit. A $3\frac{1}{2}$-inch, 40-gauge, slotted pipe, with a back-pressure valve on bottom and a short string of blank liner with a packer on top, was set on the bottom of the hole with the packer collapsed inside the casing; 2-inch wrought-iron tubing was swung just above the top of the liner; the Christmas-tree valve arrangement on top of the ground was flanged to the tubing head and the well was ready to bring in. All of the drilling mud in the hole was then displaced with clear water and this corresponding lessening of the hydrostatic head held against the oil sand allowed the well to start natural flow immediately. Some of the weaker wells required swabbing through the tubing before natural flow would begin. The wells were allowed to flow through a $\frac{1}{4}$-inch choke into a burning pit until the fluid produced became entirely free of mud and wash water before they were turned into storage.

While drilling the holes much care was exercised in the control of drilling fluid. It was seldom necessary to use artificial muds and weighting materials since the formations drilled made good natural mud. The viscosity of the fluid was kept low and the weight to about 10 pounds per gallon, or a specific gravity of 1.2, by the simple expedient of careful treatment with clear water. While drilling in and close to the Langham gas sand, however, it was often necessary to add Hagen phosphate to the mud in order to reduce the viscosity sufficiently to allow the mud to permeate the gas sand.

All rigs were equipped with two blow-out preventers of the latest types and daily practices were held by each drilling crew which insured efficient use of this equipment. The result of this careful practice is one to which Amelia can point with pride—no blow-outs.

Immediately after completion of all wells, the 122-foot steel derricks were torn down and moved to other locations. Fresh dirt was then filled in around the Christmas trees and guard rails placed around them to keep cattle away from the valves. In the case of the townsite locations, many of which were in the yards of private homes, extra precautions were exercised. All steam exhausts were muffled and after well completion all of the excess mud was pumped between the surface casing and the oil string in order to dispense with it and clean the reserve and slush pits which were then filled with fresh dirt. All of the disturbed ground around the well was reworked so that no trace of the drilling operations remained. At nearly all of these locations, the only reminder to the home owner of the well in his yard was the carefully fenced in Christmas tree standing just above ground.

Tank batteries in the townsite were built in clusters of 2–4 bat-

teries in each location. Adequate fire walls were built around the tanks and the entire location fenced with barbed wire to keep both children and cattle out of the danger zone.

Amelia is a fine example showing that cleanliness and orderliness can be maintained to a very high degree even during the rapid development of an oil field.

WELL COMPLETION PROBLEMS AND METHODS

Many and varied difficulties were experienced while attempting successfully to complete low gas-oil ratio wells which, as explained before, were assigned larger allowables than wells producing free gas with the oil. Since the oil zone was very thin and there were no consistent breaks between gas, oil, and water sand, it was found very difficult to complete the wells with their production entirely restricted to that part of the sand actually screened. The oil zone could not be produced from its entirety since it was desirable to bottom the holes as far above salt water as possible and at the same time set the casing as far below the gas-oil contact as possible in order to exclude the production of free gas from the gas cap. The casing was usually set and cemented about 10 feet below the gas-oil contact at −6,740 feet and the wells were usually bottomed about 7 feet above the water level at −6,743 feet. This practice was intended to restrict production to the 3-foot zone of sand in the open hole, which, although being a comparatively thin producing zone, would produce as much oil through a ¼-inch choke as zones of greater thickness.

The greatest completion difficulty encountered was in shutting off the free gas. In spite of the fact that casing was set below the point where free gas should not be produced, the gas followed channels in the cement behind the casing, between the cement and the walls of the hole, or through any opening available, and was produced with the oil, thus making a high-ratio well out of a well which should have been a normal low-ratio producer. Naturally this excess production of free gas held back the oil and did not allow as much to be produced as the wells were capable of yielding.

In order to complete these wells as low-ratio wells and receive the normal higher allowables it was necessary to rework all such offenders and shut off the free gas. Two methods were most commonly used to perform these secondary shut-offs: (1) the setting and cementing of an inside liner after slightly deepening the hole, and (2) squeezing cement under high pressure into the spaces evidently not very well cemented by the original cement job behind the casing.

1. The liner method, which was soon discarded in favor of the

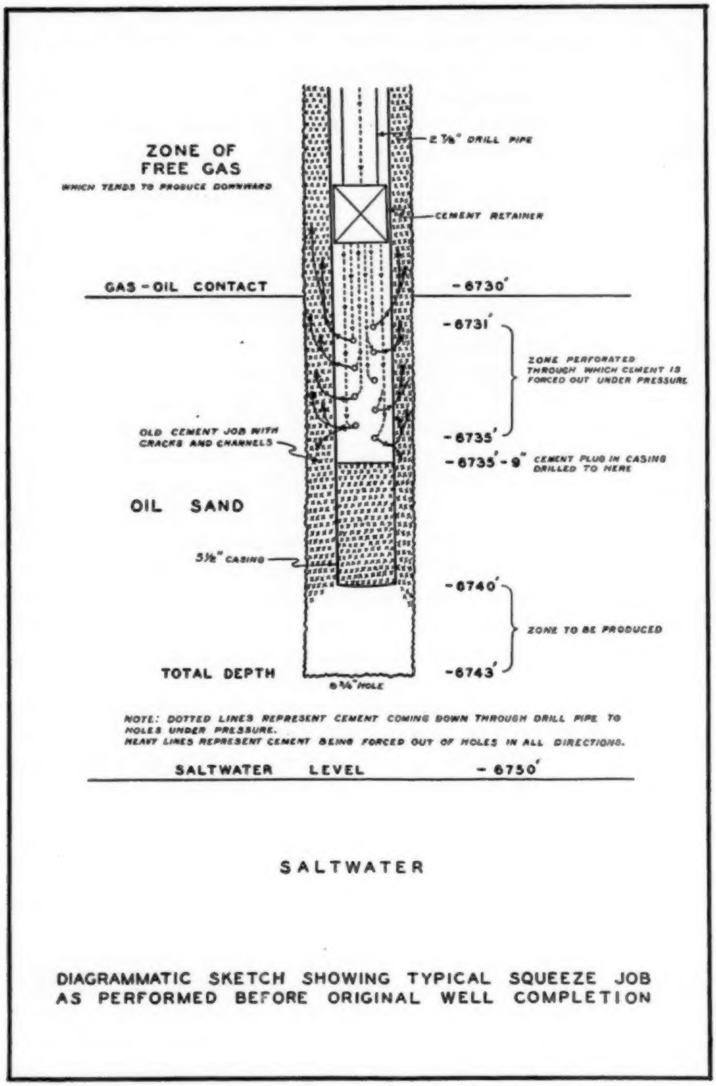

FIG. 6.—Diagrammatic sketch showing how squeeze job is performed before original completion of well.

squeeze method, was the most difficult and least advantageous to employ. It included deepening the hole a few feet, after the well had been killed and the setting pulled, and then setting and cementing in place a short blank liner, of a size just smaller than the casing ($4\frac{1}{2}$-inch, outside-dimension liner in $5\frac{1}{2}$-inch casing and 5-inch outside-dimension liner inside of 7-inch casing) on the new bottom and extending up into the casing for 40 or 50 feet. When the cement had hardened the liner was gun-perforated opposite the same zone which had formerly been produced with a high gas-oil ratio, screen was set, and the well recompleted, this time as a normal low gas-oil ratio producer.

2. The squeeze job, which has long been used to shut off salt water and to plug perforations or breaks in casing, was employed in a new rôle at Amelia when it was used to shut off free gas. The operation was performed as follows. The offending well was killed and the setting pulled; a cement retainer was set close to the bottom of the casing; a 4-foot zone gun perforated with 6–12 holes in the casing just below the gas-oil contact, the top of the zone usually 1–3 feet below the contact; a second cement retainer was set immediately above the perforated zone; and 75 sacks of cement were squeezed through the perforations into whatever voids existed behind the casing. The squeeze pressure was applied with high-pressure pumps and for different jobs varied from 2,500 to 4,000 pounds per square inch of surface pressure. The amount of cement actually squeezed behind the casing varied according to the condition of the hole and the old original cement job. The writer thinks that the cement thus squeezed in probably did not permeate the formation squeezed against but did fill all cracks, crevices, *et cetera*, in the original cement job and further strengthened the bond between the old cement and the walls of the hole, thus effecting and insuring a more perfect seal. However, it is possible that some of the cement squeezed back could have ruptured the formation along zones of weakness, such as bedding planes, small breaks, *et cetera*, and thus formed a thin pancake layer of cement between the gas and oil sands. The squeeze cement was allowed to harden and then the retainers and cement in the casing were drilled out and the well reset to produce from the same zone formerly produced. In nearly all cases the squeeze job effectively shut off all of the free gas resulting in normal allowables for those wells which had formerly been penalized because of free gas production.

This method worked so successfully and satisfactorily that it was decided to use it on all doubtful wells before original well completion. By performing the squeeze before attempting to complete the well a

delay of only one day was incurred whereas a delay of a week and longer was incurred if the job was performed as a work-over measure. The only difference in the method when it was employed before completion was the elimination of the bottom cement retainer. The cement plug inside the casing was drilled down to the point where the bottom retainer would have been set and the remainder of the cement plug was left undrilled to serve as the bottom bridge plug. From this point on the method was the same as previously described.

Five squeeze jobs were successfully performed, as work-over measures, to shut off salt water which came down from the salt-water sand, 20 feet above the Langham sand, through and around the cement job behind the casing into the screened zone.

It was noticed that where some irregular formation break, either shale or sandstone, occurred between the gas sand and the zone to be produced, a better original cement job could be obtained. These wells, with few exceptions, could be completed in the orthodox manner as normal, low-ratio producers. It appeared that the cement would form a much better bond with these breaks than it would with the soft sand. Therefore, after the policy of squeezing before completion was adopted, it was limited to those wells which had no seal between the gas and oil sands.

Several other methods and practices were tried in order to shut off the free gas but the squeeze method was found to be the only satisfactory method. In a few cases it was necessary to squeeze directly against the zone to be produced and after recompletion it was found that the formation thus squeezed against remained unharmed, suggesting that no cement had actually permeated it.

GENERAL SUMMARY OF COMPLETIONS

Total number of producing wells	115
Total number of wells which were reworked	30
Wells squeezed before completion to shut off gas	28
Wells squeezed after completion to shut off gas	9
Wells with no gas-oil seal completed normally	17
Wells with gas-oil seal completed normally	32
Wells with no gas sand completed normally	11
Wells which set inside liners when reworked	10
Wells impossible to complete with low gas-oil ratios	8
Wells squeezed to shut off salt water from above	5
Wells reworked for miscellaneous reasons	7
Wells dry and abandoned	16

PIPE LINES

Amelia has several pipe lines within the vicinity of the field. Two of these lines, the Sun Pipe Line Company and the Gulf Pipe Line Company, actually cross the producing area but were already there

before the discovery of oil. The Gulf Pipe Line Company happened to own their right-of-way in fee which entitled them to oil production; however, this acreage was pooled with Humble leases and operated by the Humble with the Gulf as a part interest owner.

The Humble Pipe Line Company's 8-inch line, extending from Louisiana to Hull and thence to the Baytown Refinery, is located about a mile north of the Amelia field. This line was connected to the field gathering system, which also belongs to the Humble Pipe Line Company and the oil is pumped directly to the Baytown Refinery. The oil produced by the only other operator, the Normandie Oil Corporation, is also bought by the Humble Pipe Line Company.

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VOL. 23, NO. 11 (NOVEMBER, 1939), PP. 1666-1672, 1 FIG.

SEDIMENTS OF SOUTH ATLANTIC OCEAN[1]

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ABSTRACT

The sediments of the South Atlantic consist of red clay, Globigerina ooze, and radiolarian ooze. Red clay is found in the bottom of basins as far south as latitude 45° or 50°. Globigerina ooze is found in the same latitudes as red clay, but generally at shallower depth. Pteropod ooze occurs on submarine ridges as far south as latitude 35°. Blue, green, and gray muds are found near shore. Glacial marine mud and diatom ooze occur in regions of cool and cold waters. Radiolarian ooze has been observed in only one area. The configuration of the sea bottom exerts a strong influence upon the character of the sediments. Transverse submarine ridges across the South Atlantic impede the northward extension of the cold Antarctic bottom current, which dissolves the shells of organisms as they sink to the bottom. This current extends farther northward on the west side of the South Atlantic than on the east, with the result that red clay is found farther north on the west side. The sediments on the ridges are more coarse-grained than those in the basins. The deposition of sediments in the ocean is affected by many factors whose influence varies from place to place. Each sediment depends on its environment.

INTRODUCTORY NOTE

PARKER D. TRASK

This paper by Dr. Pratje on the sediments of the South Atlantic Ocean was intended as a contribution to the symposium on recent marine sediments that was prepared under the auspices of the Committee on Sedimentation of the National Research Council and published by the American Association of Petroleum Geologists. Dr. Pratje is one of the foreign members of the sub-committee in charge of the preparation of this symposium and it is unfortunate that owing to a misunderstanding he did not submit his manuscript until after the symposium had gone to press. The paper he prepared is a summary of the main features of his extensive report of the sediments collected by the "Meteor" expedition in the South Atlantic, and I believe it would be of interest to members of the Association to print it in the *Bulletin*.

MORPHOLOGIC UNITS

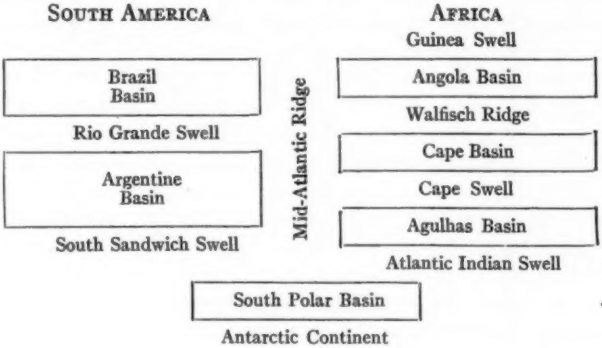
Sediments depend on the environments in which they are deposited. It is no accident that in some places Globigerina ooze and in others red clay are deposited. The sediments are influenced by the morphology of the ocean bottom, the physical conditions in the water and the climatological relations of the air above. The South Atlantic Ocean is particularly favorable for the study of the relationship of the sediments to their environment, as it exhibits a great variety of oceanographic conditions. It extends through all climatic zones from the equator to the Antarctic, it varies greatly in depth, and it has been studied more representatively than any other ocean.

The Mid-Atlantic Ridge, which extends with varying width from Iceland nearly to Antarctica, divides the ocean into basins, whose trend is more or less parallel to the coasts of the adjoining continents. These two longitudinal basins are divided by minor ridges into sub-

[1] Translated from the German by Parker D. Trask. Manuscript received, June 6, 1939.

sidiary basins. On the west side the Rio Grande Swell separates the Brazil Basin from the Argentine Basin, though on the fortieth parallel it is notched by a passage in which the water is 4,000 meters deep. The Argentine Basin is separated from the South Polar Basin by the South Sandwich Swell. However, this swell, owing to its relatively low height, exerts less influence than some of the other transverse ridges, which are higher. On the east side of the ocean, the south end of the Small Guinea Basin lies on the equator; then follows the not particularly high Guinea Swell, which forms the north border of the Angola

TABLE I



Basin. The Angola Basin is the eastern counterpart of the Brazil Basin. It is bounded on the south by the high wall of the Walfisch Ridge, which influences profoundly the geologic, hydrographic, and biologic relations in the South Atlantic. South of the Walfisch Ridge lie the Cape and Agulhas basins. These are separated from each other by the Cape Swell, which is broken through by several gaps.

All the basins are more than 5,000 meters deep and the Argentine Basin is more than 6,000 meters deep. The border of the basins is taken as the 4,000-meter contour. Table I shows the general distribution of basins in the South Atlantic.

NATURE OF SEDIMENTS

The sediments in these basins are classified into the following types.

Red clay
Globigerina ooze, Globigerina sand
Pteropod ooze
Blue, green, and gray mud
Glacial marine muds
Diatom ooze
Radiolarian ooze

Red clay.—The red clay in the South Atlantic Ocean is reddish brown to chocolate in color and ordinarily contains little calcium carbonate. Most samples contain less than 10 per cent and many have less than 5 per cent. Red clay grades into Globigerina ooze, but the transition zone is narrow. The boundary between them is taken as 30 per cent $CaCO_3$. Red clay can be regarded as the residual products of Globigerina ooze in which the calcareous parts of foraminifera and coccoliths have been dissolved, and only the insoluble inorganic residues have remained. In a few places manganese-iron concretions are found in red clay. Most of these are spherical nodules or coatings on a variety of substances; but in some places they form flat crusts on the sea bottom. Red clay is very fine-grained. The size distribution of the particles is not particularly distinctive, as it is similar to that of some blue muds.

Globigerina ooze.—The color of Globigerina ooze ranges from faintly reddish white to reddish brown. The lighter the color the more calcium carbonate the sediment contains. On the one hand is pure foraminiferal sand, which may contain almost 100 per cent $CaCO_3$, and is porous and coarse-grained. On the other hand are dark-colored oozes which have a carbonate content close to the 30 per cent limit of red clay. Most Globigerina oozes, however, contain between 60 and 90 per cent $CaCO_3$. Globigerina ooze contains other types of foraminifera than *Globigerina*, though *Globigerina* ordinarily predominate. In some samples *Globorotalia* are very plentiful and the ratio of *Globorotalia* to *Globigerina* may be as high as 3 to 4. Coccoliths ordinarily are an important constituent of the fine fractions of Globigerina ooze. A few of the sediments that were studied contain so many coccoliths that they can be considered as coccolith oozes. The size distribution of Globigerina ooze has two modes, one formed by the shells of the foraminifera and the other by fine clay particles. Intermediate sizes are relatively scarce.

Pteropod ooze.—Pteropod ooze is a variety of Globigerina ooze in which pteropods are plentiful. The commonest types of pteropods have sharply conical forms, but the shells ordinarily are broken. They seem to be very easily soluble and are rarely observed in samples from deep water. The percentage of pteropod shells never is very large, except in a few thin individual layers. A few per cent suffices to designate the sediment as a pteropod ooze. The carbonate content ordinarily is high.

Blue, gray, and green muds.—The terrigenous blue, gray, and green muds are separated from one another by their color. All gradations between them occur. Blue mud in general is a reduced form of the

other muds. All these muds reflect the influence of land, because of their location relatively near shore. They however extend down into the basins and grade into red clay. Their content of calcium carbonate and foraminifera is small and some samples contain significant quantities of diatoms and glauconite. Blue mud commonly smells of hydrogen sulphide, thus indicating the decomposition of organic constituents. The dark color is caused by iron sulphide. When this iron is oxidized it changes the color of the mud.

Glacial marine mud.—Glacial marine mud contains material of ice-raft origin in addition to substances ordinarily found in terrigenous muds. The size distribution, as in Globigerina ooze, is in two main parts, but the coarser part is more variable, owing to varying size of the material transported by floating ice. The fine fractions are separated from those of the blue, gray, or green muds by the greater amount of quartz. They also contain considerable quantities of diatoms; in fact in places they grade into diatom ooze. Their content of calcium carbonate generally is small; and their color is greenish gray to brownish gray.

Diatom ooze.—Pure diatom ooze, which consists predominantly of diatoms, is not widespread. Diatom ooze is extraordinarily light, felt-like, and elastic. It is commonly bright yellow or bright brown in color. It contains practically no calcium carbonate and very little clayey or sandy matter. It grades into glacial marine deposits, when the content of material of glacial origin increases. Since diatoms are exceedingly small, they must be present in considerable quantities in order to form a significant part of the sediments. Consequently diatom ooze is regarded as most closely related to glacial marine sediments. However, it should be mentioned that pure diatom ooze occurs in very shallow water off the coast of southwest Africa in Walfisch Bay, where cold upwelling water prevails. The diatom ooze in this area differs from true diatom ooze in color, which is bright green, but otherwise it is similar to other diatom oozes.

Radiolarian ooze.—Radiolarian ooze is a form of red clay in which radiolaria are plentiful. It has the same color and other characteristics as red clay. Radiolarian ooze previously has not been recognized from the South Atlantic Ocean, but one sample found on the "Meteor" expedition must be regarded as radiolarian ooze.

DISTRIBUTION OF SEDIMENTS

These types of deep sea deposits are distributed in the South Atlantic in the following way (Fig. 1). The Brazil Basin is covered with red clay, except around the borders, where Globigerina ooze is

present. The sediments of the Angola Basin consist mainly of Globigerina ooze except in the northeast part where red clay occurs. The deposits in the north part of the Argentine Basin consist of red clay, and in the south part, of glacial marine mud. Blue, green, and gray mud are found along the west edge of the basin. Globigerina ooze pre-

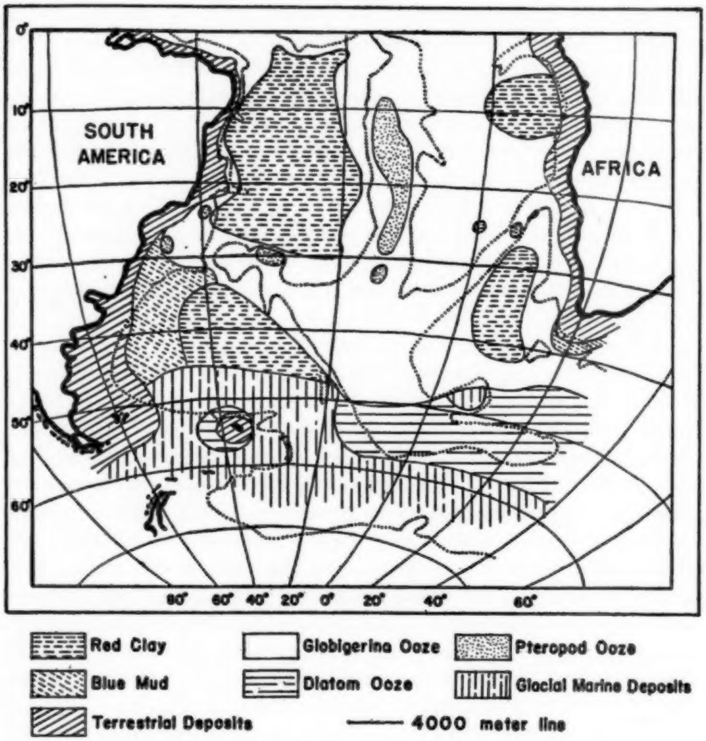


FIG. 1.—Distribution of sediments in South Atlantic Ocean.

dominates in the Cape Basin, but red clay is present in the deepest part of this depression. The north part of the Agulhas Basin is covered with Globigerina ooze; the south part, with diatom ooze. The South Polar Basin consists mainly of glacial marine mud and associated diatom ooze.

The Mid-Atlantic Ridge, the Guinea Swell, the Rio Grande Swell, the Walfisch Ridge, and the greater part of the Cape Swell are covered

with Globigerina ooze, and in places with pteropod ooze. The South Sandwich Swell and a small part of Cape Swell carry glacial marine mud. The Atlantic-Indian Swell is covered with diatom ooze.

FACTORS INFLUENCING DEPOSITION OF PELAGIC SEDIMENTS

This discussion of the distribution of sediments has been given in broad generalities in which minor variations have been ignored, but it indicates several relationships about the deposition of sediments in the ocean.

Climatic zones are indicated mainly by pteropod ooze, which extends to about 35° S., and then is completely lacking. Also, Globigerina ooze and red clay, which are associated genetically, have a common southern limit between 45° and 50° S. Their southern boundary is the same as the northern extension of glacial marine mud and diatom ooze. The distribution of floating ice determines the extent of glacial marine sediments.

Depth of water particularly influences the deposition of red clay and Globigerina ooze, though in some places red clay is found at shallower depths than Globigerina ooze. Depth of water also affects the deposition of blue mud, pteropod ooze, and terrigenous shelf deposits, though to a lesser extent than red clay or Globigerina ooze.

With respect to the influence of currents, the effects of the surface, intermediate, and bottom currents have to be distinguished. The surface currents act indirectly, as they determine the distribution of the organisms whose shells eventually form part of the sediments. Since the temperature of the surface water plays an important rôle in the distribution of organisms, the influence of the surface currents is associated with the effect of climate. However, the influence of currents in some places is different from that of climate. For example, the trade winds off the coast of Africa blow the warm surface water away from shore, thus causing the cold deep water to rise to the surface. With the resulting drop in temperature the number of foraminifera decreases and the quantity of diatoms increases. Lime-poor and diatom-rich sediments result. The reverse action takes place on the Brazil coast where the warm water brought by the currents causes the growth of corals and the deposition of calcareous deposits.

The bottom currents act directly on the sediments and thus modify the effect of other factors. As is seen from the distribution of sediments in Figure 1, carbonate-poor red clay and blue mud are much more widespread on the west side of the South Atlantic than on the east side. In the Argentine Basin they extend to the Rio Grande Ridge and in the Brazil Basin they begin immediately north

of this ridge. On the east side of the Atlantic, in the Cape Basin, which corresponds with the Argentine Basin on the west, red clay extends to the Walfisch Ridge, but in the Angola Basin, on the north, it is encountered only in a relatively small area in the northeast part. The low content of carbonate is ascribed to solution by the bottom current. In fact the distribution of red clay indicates the existence of this bottom current. This current, which arises in the Antarctic regions, on the west side of the South Atlantic, because of the notch in the Rio Grande Swell proceeds farther north than on the east side. It extends northward toward the equator through the Romanche Deep and passes over the Mid-Atlantic Ridge to the north side of the Angola Basin, thus accounting for the presence of red clay there. On the east side of the South Atlantic the Walfisch Ridge forms a barrier to the Antarctic bottom current, so that it can not pass farther north. Consequently in the same ocean in the same latitude and in the same depth of water, different types of sediments occur. The morphology of the sea bottom is a dominant factor in this varying distribution of sediment and in places its influence extends a long way.

The effect of the intermediate currents is mainly one of sorting. They are stronger than the bottom currents and on submarine ridges and swells hinder the deposition of fine particles, so that in those places relatively coarse-grained deposits are laid down, whereas the clayey constituents come to rest in the deeps. In this way different types of sediments may be deposited in different depths of water, in spite of distance from land or distribution of plankton. Globigerina and pteropod oozes, as may be seen from Figure 1, are characteristic deposits of the ridges and swells; clay is completely lacking.

CONCLUSION

Many factors influence the deposition of sediments in the ocean. The effect of the individual factors varies so widely in different places that each particular sediment is likely to be different from its neighbor. In other words, the nature of each sediment is determined by the environmental conditions of deposition.

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STANDARD PERMIAN SECTION OF NORTH AMERICA[1]

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ABSTRACT

The writers advocate the classification of the American Permian as a system composed of four series, named, from oldest to youngest, the Wolfcamp series, the Leonard series, the Guadalupe series, and the Ochoa series.

ACKNOWLEDGMENT

The writers are indebted to Hugh D. Miser, James Steele Williams, and Philip B. King of the United States Geological Survey for generous advice and criticism, and particularly for the recommendation of the name *Guadalupe* as most suitable for the third division of the Permian. King's unpublished work on the Guadalupe Mountains was very helpful in formulating the classification.

Grateful acknowledgment for important editorial coöperation is also due C. W. Tomlinson, chairman of the Permian subcommittee of the geologic names and correlations committee of the American Association of Petroleum Geologists, and to Robert H. Dott, director of the Oklahoma Geological Survey, and Raymond C. Moore, State geologist of Kansas, members of the Permian subcommittee.

CLASSIFICATION

The most nearly continuous deposition during the Permian period in America, so far as known, took place in and around the Delaware basin of West Texas and southeastern New Mexico. The Permian sediments in the Delaware basin are more than 10,000 feet thick. The lower 6,000 feet are marine beds; the upper 4,000 feet are saline residues and non-marine clastics.

In and around the Delaware basin the marine Permian exhibits three facies. In the depositionally low areas are the "basin"[2] or "pontic,"[3] sparingly fossiliferous, essentially clastic sediments. Around the

[1] Manuscript received, August 11, 1939.

[2] P. B. King's term.

[3] E. Russell Lloyd's term.

margins of the basin are the "marginal"[2] or "reef"[3] belts of highly fossiliferous limestones. Beyond these marginal belts are the "shelf"[2] or "lagoonal"[3] deposits, characterized by fossiliferous limestones and shales, dolomitic limestones, saline evaporites and onshore clastics, which extend over areas hundreds of miles wide.

The larger sedimentary units include deposits of all three facies. Correlations of these major units between the Delaware basin and its marginal belts are well established. Some of the correlations between the marginal belts and the adjacent shelf areas are problems still under debate, which can be solved only by future field and subsurface work.

The writers advocate the classification of the American Permian as a system composed of four sedimentary divisions of series rank. The proposed classification of the Permian into series is based on the thick and nearly continuous section exposed by outcrops and wells in and immediately adjacent to the Delaware basin. Correlations between this standard section and the rest of Texas, New Mexico, Oklahoma, Kansas, Nebraska, Wyoming, Idaho, Utah, Arizona, and other states and countries can be made, revised, and revised again without altering the validity of the standard section.

The proposed divisions[4] of the Permian system are as follows.

Ochoa series
Guadalupe series
Leonard series
Wolfcamp series

The writers recognize that systemic boundaries can be finally decided only by substantial agreement in international usage. If such agreement alters the proposed standard section, it is very probable that a new systemic boundary so chosen will be one of the series boundaries herein proposed.

Wolfcamp series.—The first and lowest of these divisions, the Wolfcamp series, includes the oldest Permian rocks of the Glass Mountain region. It comprises beds that have been referred to the Wolfcamp formation (restricted),[5] which is thus raised to series rank. In the Glass Mountains the Wolfcamp series consists of about 600 feet of limestones, limestone conglomerates, and shales. In West Texas the Wolfcamp rests with angular unconformity on rocks ranging in age from pre-Cambrian to upper Pennsylvanian and is unconformably overlain by the succeeding Leonard series.

[4] For references to the literature on the names Wolfcamp, Leonard, and Guadalupe see: M. Grace Wilmarth, "Lexicon of Geologic Names of the United States," *U. S. Geol. Survey Bull. 896* (1938), and Philip B. King, "Geology of the Marathon Region, Texas," *U. S. Geol. Survey Prof. Paper 187* (1937).

[5] King, *op. cit.*, p. 94.

Although the Wolfcamp fauna includes many genera that range up from the Pennsylvanian, it is characterized by the abrupt incursion of the fusulinid genera *Schwagerina* s. s., *Pseudoschwagerina*, and *Paraschwagerina*, by the presence of the ammonoid genus *Properrinites*, the brachiopod genus *Parakeyserlingina*, and other distinctive Permian genera.

The great hiatus present at the base of the Wolfcamp series in West Texas may be partly filled in regions removed from the Marathon disturbance by beds older than the type Wolfcamp. In that event the authors recommend that the base of the Wolfcamp series be drawn at the first important hiatus below strata characterized by the genera mentioned above.

Leonard series.—The second division, the Leonard series, comprises beds heretofore assigned to the Leonard formation, which is thus raised to series rank. At the type locality on the south face of the Glass Mountains the Leonard is more than 1,800 feet thick and consists of limestones and dark siliceous shales. It rests disconformably on the Wolfcamp and underlies the Word formation of lower Guadalupe age with seeming conformity.

Prorichthofenia and *Scacchinella* are exceptional coral-like brachiopods common in the Leonard, and *Dictyoclostus bassi* McKee (*Productus ivesi* of authors, not Newberry) is a common, diagnostic species; *Perrinites* is representative of the ammonoids; and the common fusulinids are primitive types of *Parafusulina*, that is, those in which the cuniculi are rather small and appear late in the ontogeny.

Guadalupe series.—The third division, the Guadalupe series, comprises beds that have been classed as the Guadalupe group (restricted),[6] which is thus raised to series rank. At the type locality, the south end of the Guadalupe Mountains, the Guadalupe series, 4,100 feet thick, consists of 2,300 feet of sandstone overlain by 1,800 feet of (Capitan) limestone. It rests on the Bone Spring limestone of Leonard age. A sparse collection of fossils from the topmost beds of Bone Spring limestone was originally classified by Girty as the oldest part of the Guadalupian fauna, but the present note, adopting a preferable restricted usage,[6] confines the faunal term Guadalupian to fossils of post-Leonard age.

Because of erosion the youngest beds of the Guadalupe series are missing from the type section. A more complete section was penetrated by Getty Oil Company's Dooley No. 7 in Sec. 24, T. 20 S., R. 29 E., Eddy County, New Mexico, from 1,020 to 6,270 feet, a total thickness of 5,250 feet.

[6] Wilmarth, *op. cit.*, p. 884.

In the Delaware basin the Guadalupe series is represented by a sandstone facies known as the Delaware Mountain sandstone, which is 3,000 to 3,500 feet thick at its outcrop in the Delaware Mountains and is there divided into three approximately equal formations. The sandstones of the first or lower formation, which are much coarser than the average sands of the Permian, pinch out against a marginal ridge on the north side of the Delaware basin. The sediments of the middle formation are also sandstones that contain some interbedded limestones. Toward the north these sandstones grade laterally into limestones which rest unconformably on beds of upper Leonard age. The sediments of the upper formation are mainly sandstones, but with more numerous limestone beds; these sandstones and thin limestones grade laterally into the solid massive limestone of the Capitan reef.

The Guadalupe series in and around the Delaware basin can be subdivided into two paleontologic units. The lower unit, which includes the lower and middle formations of the Delaware Mountain sandstone, the equivalent Word formation, and certain limestones of the marginal belt, contains the ammonoid *Waagenoceras* and is characterized by species of the genus *Parafusulina* that are markedly more advanced than the primitive species of the same genus in the underlying Leonard series. In the upper unit, which includes the upper formation of the Delaware Mountain and the equivalent Capitan limestone, the fusulinid genus *Polydiexodina* is prominent and characteristic. *Waagenoceras* is still present but is associated with a more advanced, related genus *Timorites*.

Ochoa series.—The writers of this note propose to call the fourth and uppermost division of the Permian the Ochoa series after Ochoa post office in T. 24 S., R. 34 E., Lea County, New Mexico. In the deep basin underlying this vicinity almost continuous deposition took place during Ochoa time.

The Ochoa series, which is designed to include all upper Permian sediments of post-Guadalupe age, consists largely of evaporites and attains a subsurface thickness of considerably more than 4,000 feet. Four distinct subdivisions are recognized, which, at present, are designated as Lower Castile, Upper Castile, Rustler, and Dewey Lake.[7]

The Lower Castile is confined to the Delaware basin, where it rests on the Delaware Mountain sandstone. In places a basal conglomerate is present. Outside the Delaware basin the Upper Castile overlaps onto and rests unconformably on beds of Guadalupe age.

[7] The Dewey Lake is named in a forthcoming paper by Lincoln R. Page and John Emery Adams, "Stratigraphy, Eastern Midland Basin, Texas."

Outcrops of beds of Ochoa age are found in Eddy County, New Mexico, and Culberson County, Texas, but these outcrops are not representative of the thick sequence found in the subsurface type locality. The type section has been penetrated in many wells and is represented by samples and cores on file at the Bureau of Economic Geology, Austin, Texas.

Only a few undetermined pelecypods have been found in the Rustler limestone. The remainder of the series appears to be unfossiliferous.

CORRELATION

The writers believe that the paleontologic and stratigraphic evidence at hand is sufficient to justify the application of these standard series beyond the limits of the Delaware basin, although no one author is prepared to accept sole responsibility for all the proposed correlations that follow. The writers recognize that the precise boundaries of the standard series in other provinces can not yet be set with absolute finality, but must remain subject to corrective adjustment in many places.

Wolfcamp series.—Wolfcamp equivalents include the Hueco formation (restricted) of the Diablo Plateau and the Abo formation of New Mexico.

In central Texas the Wolfcamp series extends from a horizon 50–100 feet below the Saddle Creek limestone up to about 200 feet above the Coleman Junction limestone, including portions of the Cisco and Wichita-Albany groups of older nomenclature. Both limits there coincide with relatively sharp faunal changes and with disconformities of considerable areal extent.

The Wolfcamp series of northern Oklahoma, Kansas, and Nebraska includes beds from the disconformity immediately above the Brownville limestone up to a horizon near the top of the Herington limestone. The writers recommend that in Oklahoma the term *Wanette* be dropped in favor of Wolfcamp series.

The very pronounced angular unconformity found at the base of the Wolfcamp in West Texas decreases toward the north and east.

Leonard series.—Leonard equivalents include the Bone Spring formation of the Sierra Diablo and the Delaware and Guadalupe mountains, the Yeso and possibly the San Andres formations of New Mexico, and, in terms of older nomenclature, part of the Wichita-Albany group plus all the Clear Fork group plus part of the Double Mountain group in central Texas.

In Oklahoma and Kansas the Leonard series extends from the horizon near the top of the Herington limestone up to the top of the

Dog Creek shale—that is, to the base of the Whitehorse group. Consequently the formations of the Big Blue and Cimarron series of Kansas and Nebraska should be reclassified according to assignments in the Wolfcamp, Leonard, and Guadalupe series. The writers recommend that in Oklahoma the term *Minco* be dropped in favor of Leonard series.

The horizon of the upper boundary of the Leonard series can be traced confidently from west-central Texas to Kansas.

Guadalupe series.—The Guadalupe series includes the Whitehorse group and equivalent beds in Texas, Oklahoma, and Kansas. The Cimarron series of the northern Mid-Continent region should be abandoned, and its constituent strata reclassified as belonging to the Leonard series and the Guadalupe series.

Ochoa series.—Outcrops of Ochoa age are not recognized by the writers along the eastern margin of the Permian basin in Texas or in the Texas Panhandle, and the Ochoa series appears to be absent in Oklahoma, Kansas, and Nebraska. Beyond the limits of the Delaware basin it seemingly pinches out eastward and northward in the subsurface before reaching the outcrops.

DISCUSSION

Darsie A. Green, The Pure Oil Company, Tulsa, Oklahoma.—In Oklahoma the base of the Wanette was intended to be correlative with the base of the Admire group of Kansas. It now appears that a mis-correlation of the Brownville limestone in central Oklahoma caused this contact to be placed at the wrong unconformity (*Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 12, December, 1937, p. 1519).

In a previous publication (Vol. 20, No. 11, November, 1936, p. 1457) two unconformities are shown, one about 100 feet below the Grayhorse limestone and another about 100 feet above the Grayhorse. It now appears that the upper unconformity, which occurs about half way between the base of the Foraker and the top of the Grayhorse, is correlative with the base of the Admire group of Kansas. Consequently the base of the Wanette should be moved up to this upper break, which can be traced over a much greater area than the unconformity that occurs below the Grayhorse limestone.[8]

ADDENDUM

Ronald K. DeFord, Midland, Texas, editor of the projected Permian volume.—*Permian volume.*—The writers believe that their standard section, based on the Delaware basin and its immediate environs, including the Guadalupe Mountains, Sierra Diablo and the Glass Mountains, has a validity that is not dependent on correlations with other important Permian provinces. Their correlations in this note are made in the light of their present knowl-

[8] Note by writers of the major article.—The Wanette is equivalent to the Wolfcamp series.

edge and are a challenge to experts to modify them according to more accurate detail or to prove them wrong.

The stimulus to Permian thought resulting from the proposal of a standard section and from the challenge of attempted long-range correlation should be beneficial to the Permian volume. This volume will itself be the test of this present preliminary work. No one must assume that the correlations, or even the standard section, will be imposed willy-nilly on the many authors of the volume. It is the function of the volume to classify the Permian of the western interior United States and to re-create its history.

In the matter of correlation one difference deserves special notice here. A number of geologists looking at the Permian through the West Texas end of the telescope think that beds of Ochoa age are absent in Oklahoma and Kansas. Many Oklahoma and Kansas geologists, who look through the other end, think that Ochoa sediments are probably present in their geologic column. The upper part of the Ochoa, say the West Texans, appears to pinch out in the subsurface within the West Texas area. But disregard the upper part and consider the lower part of the Ochoa, which attains a thickness of 1,700 feet or more and is known to be confined to the Delaware basin. No matter what is decided about the upper part, the Oklahomans and Kansans are confronted with the problem of which hiatus in their geologic column represents the lower part.

Recent papers.—Rogatz has[9] recently published a paper on the geology of the Texas Panhandle; Hemsell,[10] on the Hugoton gas field and its relation to the Texas Panhandle. Mohr's paper[11] in this issue of the *Bulletin* correlates Permian beds from Texas to Nebraska. Norton[12] has in press a definitive paper on the Kansas redbeds. An attempt to apply the standard section to these papers in accordance with the correlations proposed by the authors of the standard section should be of considerable interest. Perhaps it will stimulate corrections by geologists who are better informed than the writer.

The information is not at hand to decide where in the Panhandle section to place the horizon of the base of the Wolfcamp (that is, the "horizon 50–100 feet below the Saddle Creek limestone," or the "disconformity immediately above the Brownville limestone"). Rogatz does not attempt long-range correlations, though he uses the terms Cisco, Wichita-Albany, Clear Fork, San Angelo, Blaine, Whitehorse, Quartermaster, in his illustrations. He divides the lower (Permian and Pennsylvanian) part of his section into lithologic "zones," called in descending order: "Zone A," "Zone B," "Zone C," "Zone D," "Zone E."

Figures 7 and 19 of Rogatz's latest article place the base of the Permian at the base of "Zone D"; Figures 8, 12, and 22 place it at the top of "Zone D," but on these figures a wavy line shows the base of "Zone D," as an un-

[9] Henry Rogatz, "Geology of Texas Panhandle Oil and Gas Field," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 7 (July, 1939), pp. 983–1053. *Ibid.*, Vol. 19, No. 8 (August, 1935), pp. 1089–1109.

[10] Clenon C. Hemsell, "Geology of Hugoton Gas Field of Southwestern Kansas," *ibid.*, Vol. 23, No. 7 (July, 1939), pp. 1054–67.

[11] C. L. Mohr, "Subsurface Cross Section of Permian from Texas to Nebraska," *ibid.*, Vol. 23, No. 11 (November, 1939), pp. 1694–1711.

[12] George H. Norton, "Permian Redbeds of Kansas," *ibid.*, Vol. 23, No. 12 (December, 1939), in press.

conformity and a straight line is used at the top of "Zone D." Figures 14 and 16 also place "Zone D" in the Pennsylvanian. Figure 9 shows "Zone B" resting directly on "Zone E," and Figure 10 shows "Zone B" resting on pre-Cambrian. Figures 21 and 24 show "Zone C" resting directly on "Zone E." A wavy line on Figure 22 indicates an unconformity between "Zone D" and "Zone E," but this figure also shows an unconformity between "Zone D" and "Zone B," marked by the absence of "Zone C"; it and Figure 12 are the only illustrations showing an unconformity at the top of "Zone D."

The text (p. 1040) includes "Zone D" in the Permian. It is possible that the base of "Zone D" is the base of the Wolfcamp. The evidence of the fusulinids should be decisive, but it is unavailable to the writer. The top of the Wolfcamp seems to be near the top of "Zone B." Tentatively, then, the Wolfcamp series may be equivalent to "Zones B, C, and D."

The Leonard series extends from the top of the Wolfcamp upward to the base of the Whitehorse. The Whitehorse belongs in the Guadalupe series. The "Quartermaster" is shown only in Figure 24, and the "Triassic?" in Figures 8 and 24; the data are insufficient to permit comment on these beds.

Hemsell's paper was helpful in making the foregoing correlations. Hemsell places the base of the Permian in the Panhandle tentatively at the base of "Zone C." The top of the Wolfcamp series would be near the top of the Herington limestone on his Figure 2B. The Leonard series extends from near the top of the Herington (shown by the horizontal line at 2,490 feet on his Figure 2A) up to the base of the Whitehorse. The Whitehorse plus Day Creek represents the Guadalupe series. The proposed correlations suggest that the Ochoa series may be represented by a hiatus between the Day Creek and the Quartermaster, and that the Quartermaster may be Triassic.

The same remarks would apply these correlations to Norton's forthcoming paper: top of Wolfcamp series is near top of Herington; Leonard series up to base of Whitehorse; Guadalupe series represented by Whitehorse and Day Creek; Ochoa series supposedly represented by hiatus between Day Creek and Quartermaster or Big Basin.

On the cross section from Texas to Nebraska, Mohr's Wolfcamp, Stratford, and Wanette would represent the Wolfcamp series. In Texas his Leonard plus his San Angelo and "Blaine" and in Oklahoma his Minco would represent the Leonard series. His Whitehorse and Custer would represent the Guadalupe series, except that his northern Custer, at least, includes the Quartermaster.

Personal communications.—From H. H. Bradfield (September 9, 1939): In reply to your question concerning the base of the Wolfcamp or Permian in the Texas Panhandle in reference to Rogatz's zones, I must confess that I am at loss to know just what he includes in his "D zone," and I have never seen a fossiliferous normal section away from the top of the ridge, which he has zoned. Both the "C zone" and "D zone" dolomites grade into normal marine limestones off structure as do the granite washes of the "D" and "E" zones, and I am not sure how much of these limestones below the top of the "C zone" (Elm Creek) he places in the "D zone." The "D zone" beds present on top of the Panhandle ridge are undoubtedly well above the base of the Wolfcamp, and I believe that in many places the base of the Wolfcamp is well within the "E zone"; off structure the base of the Wolfcamp may be as high as the base of his "D zone."

From C. D. Cordry (September 18, 1939): With reference to Rogatz's

zones, this horizon would lie within the "E zone," where the "E zone" is fully developed away from the uplift proper. As can be readily seen, the base of the "E zone" descends stratigraphically as this "zone" is traced basinward away from the uplift. The base of this "zone" is very difficult to determine under such conditions, and I do not know what criteria Rogatz uses in determining this point. In northeastern Moore County the base of the Wolfcamp is found approximately 600 or 700 feet below the base of the "D zone." In this area it is to be noted that the "D zone," as shown by Rogatz, has increased considerably in thickness over that found nearer the uplift proper.

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SALT, POTASH, AND ANHYDRITE IN CASTILE FORMATION OF SOUTHEAST NEW MEXICO[1]

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ABSTRACT

The Castile and Rustler formations have a combined thickness of 4,450 feet and compose one of the thickest evaporite sections in the world.

Continual accumulation of concentrated saline water beneath the surface water in the Delaware basin raised the level of the concentrated water to the point where it caused epoch-making events in upper Permian history. The inflow of marine water was less than evaporation and Capitan reef building and associated petroleum deposition was stopped. Further excess evaporation caused deposition of evaporites in the Delaware basin. This event marks the close of Capitan time and the beginning of Castile.

The lower Castile is confined to the Delaware basin. In places its thickness attains 2,000 feet. It is composed of banded anhydrite, white anhydrite, and white halite, but lacks potassium minerals.

Subsurface study discloses many hundred feet of depositional relief on the basin floor near the end of lower Castile time. This condition is responsible for unsuccessful attempts to make a structural correlation across the Delaware basin on the base of the upper Castile ("Main Salt").

At present potash is the mineral product of greatest economic importance in the Castile formation. Two mines are producing from the upper Castile. The deposits near Carlsbad are among the finest in the world. The known potash reserve plus the large unexplored area favorable for commercial deposits indicates that the United States need have no fear of future potash shortage.

A study of two subsurface cross sections shows many interesting features about evaporite sedimentation.

INTRODUCTION

Many publications have discussed the Castile formation, but no detailed description of the formation has been published. The purpose of this paper is presentation of detailed information on its subsurface occurrence in Southeast New Mexico, More than 95 per cent of the formation is composed of salts deposited by evaporation of saline water. Little is known about evaporite sedimentation, and it is hoped that the data presented will supply a part of the basis for the solution of this problem.

EXTENT OF CASTILE

Figure 1, which is an outline map of the West Texas-New Mexico Permian basin, shows the general extent of the Castile formation and the main topographic features of its basin floor. The only surface exposure is in the western part of the Delaware basin (the hatched area of Figure 1), where the basal 800 feet of the formation is present and is composed of gypsum derived from the weathering of anhydrite. The buried part of the formation underlies an area more than 200

[1] Read before the Association at Oklahoma City, March 22, 1939. Manuscript received, August 11, 1939.

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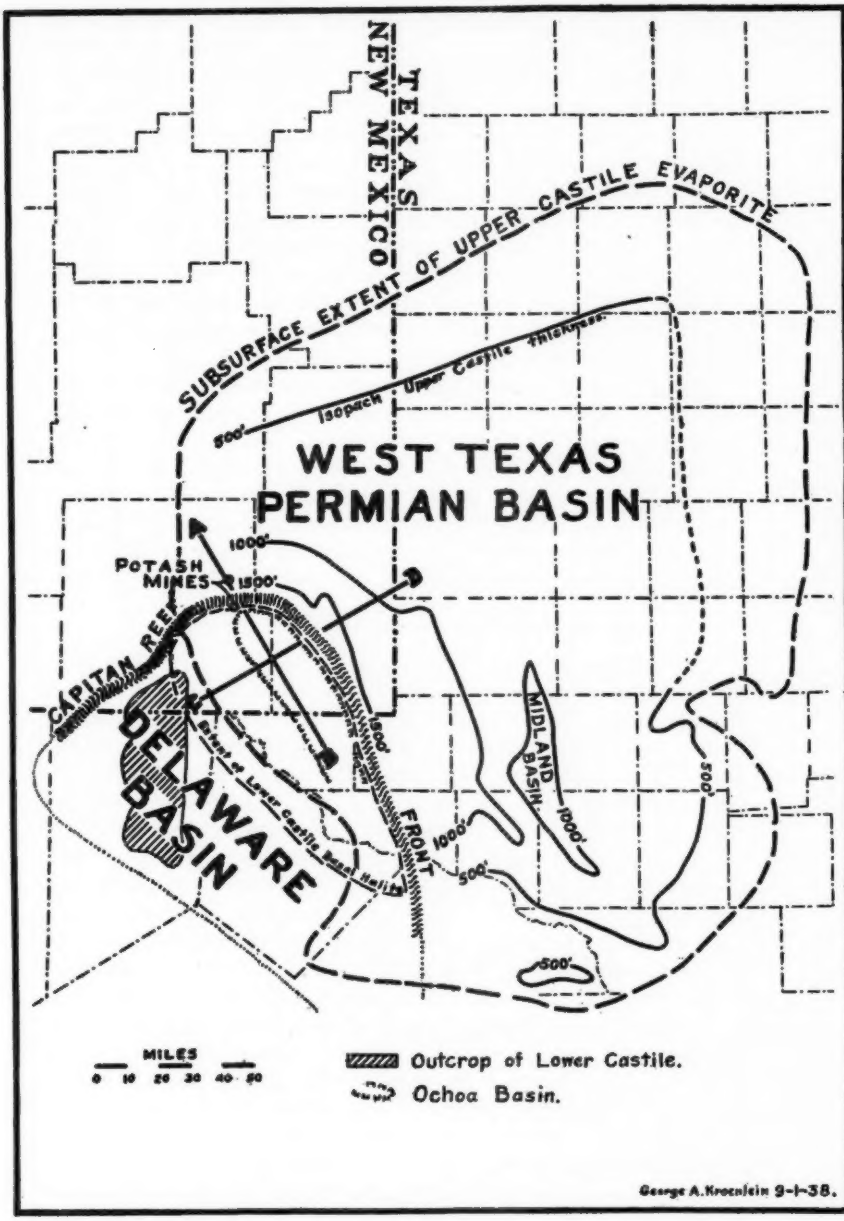

FIG. 1.—Map of West Texas and Southeast New Mexico showing location of basins and cross sections *AB* and *CD*.

miles in diameter, which is outlined by the dashed line marked "Subsurface Extent of Upper Castile Evaporite" on Figure 1. Its maximum thickness of 4,000 feet is developed in the east-central part of the Delaware basin.

Two cross sections (Figs. 2 and 3) pass through the area of greatest thickness. These cross sections are based on sample logs made by the author from microscopic examinations of cuttings from wells drilled in oil exploration. In each cross section, the well logs are assembled on a horizontal line and the base of Anhydrite No. 24 is used as the datum. This assembly shows the depositional relationship better than the customary structural assembly. The base of Anhydrite No. 24 was selected for two reasons: first, because the base of Anhydrite No. 24 marks the approximate change from gray halite below to pink halite above; secondly, because it marks the time during which the saline lake was most restricted in area, and its water sufficiently concentrated in potassium to deposit commercial potash.

Only the top portion of the Castile is present outside the Delaware basin. It is natural to call this division, which is often called the "Main Salt" by subsurface workers, the upper Castile.

LOWER CASTILE: STRATIGRAPHY AND HISTORY

Death of Capitan reef.—Near the end of Capitan time, the Delaware basin was an abrupt deep in the larger West Texas-New Mexico Permian basin. The top of the Delaware Mountain formation, which formed the floor of the Delaware basin, was approximately 1,800–2,000 feet below the top of the reef that formed the basin rim. Except for a narrow shallow-sea connection at the extreme south end, this basin was closed. Outside the basin at a considerable distance behind the reef, deposition of anhydrite and salt was contemporaneous with the building of the reef. This evaporite deposition indicates a dry climate with a high rate of evaporation. Naturally this evaporation went on in the Delaware basin, and the water containing salt in excess of the marine water sank to the bottom. The continual accumulation of concentrated saline water raised the brine level to a point where it endangered reef life. The low position of the last period of reef growth during Capitan time indicates that the surface water level was falling because the marine water supply did not match evaporation. Continued excess of evaporation lowered the surface water level and associated reef environment to a point where the accumulated brine killed life on the reef. This caused the death of the reef and closed Capitan time. Further excess of evaporation over marine inflow resulted in concentration sufficient to deposit anhydrite and marks the beginning of Castile deposition.

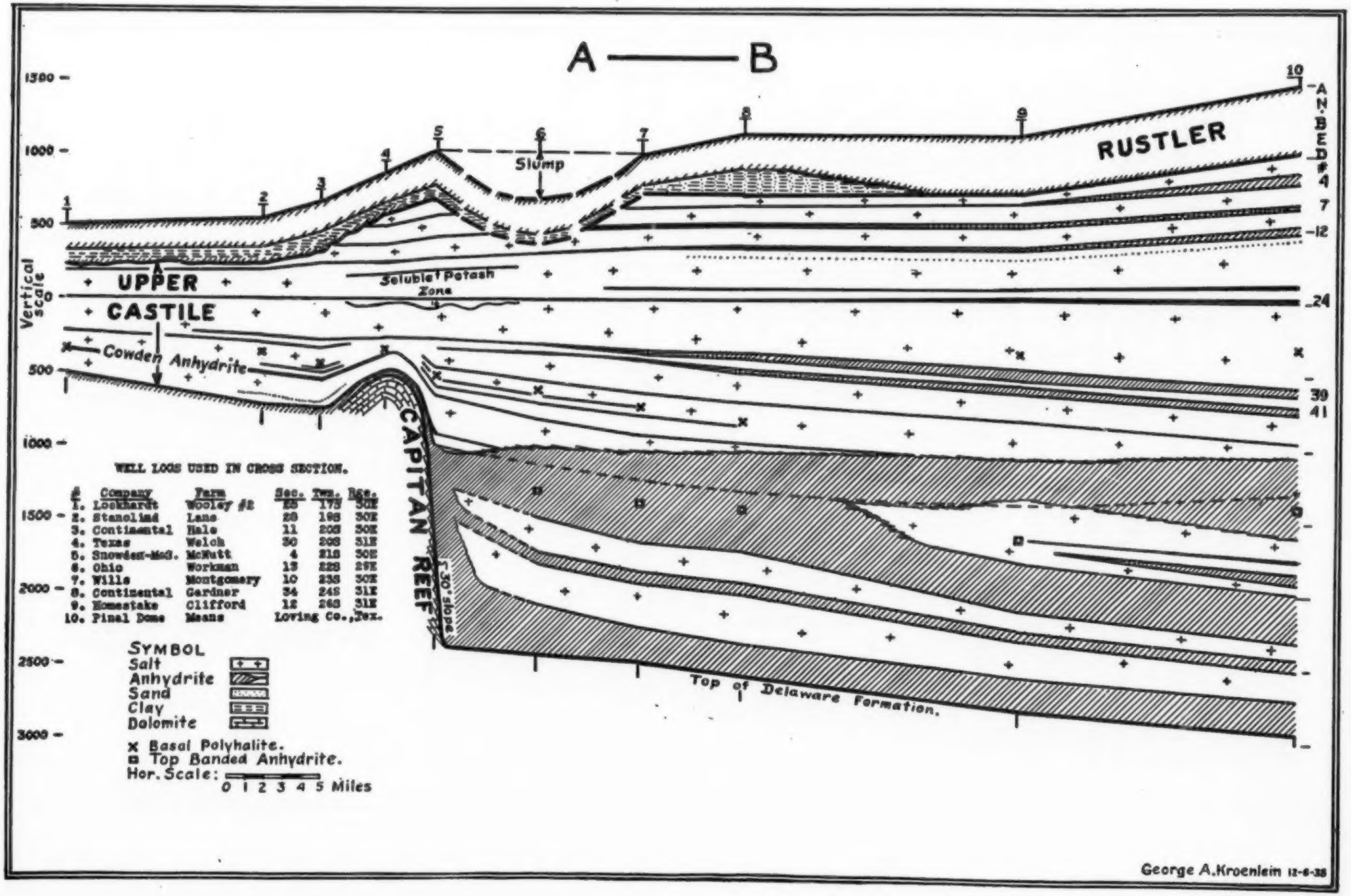

FIG. 2.—North-south cross section *AB*. Location shown on Figure 1.

Deposition of lower Castile.—The lower Castile formation is confined to the Delaware basin and appears to be conformable on the underlying Delaware Mountain formation. It is composed of banded anhydrite, white anhydrite, and colorless halite. A minor amount of gray clay and occasional quartz crystals are present. A noticeable feature is the purity of the white anhydrite and halite.

The banded anhydrite is composed of alternate laminae of pure white anhydrite and brown calcitic anhydrite. The best description of this banded anhydrite is in Udden's[8] description of a core from the Flood diamond-drill hole in southeastern Culberson County, Texas. An average of 185 layers or bands of white anhydrite and associated brown anhydrite are present in one foot of formation. It is possible that this deposition is in seasonal cycles and one foot represents 185 years of time. The white laminae average three times the thickness of the brown. Udden states that the brown discoloration is caused by bitumen. Small showings of oil reported from the banded anhydrite in recent test wells drilled in the southern part of the Delaware basin may represent accumulation of this bitumen.

The portion of the lower Castile containing banded anhydrite is approximately 1,800 feet thick in the south part of the Delaware basin and progressively decreases to 700 feet adjacent to the reef on the north. The form of the deposit indicates that the water bearing the calcium sulphate came into the Delaware basin from the south and west.

A nearly uniform halite zone, the base of which is approximately 225 feet above the base of the banded anhydrite, is confined to an oblong area in the north part of the Delaware basin. Its limits are shown on Figure 1 by a dashed line labeled "Extent of Lower Castile Basal Halite." The maximum thickness of this halite zone, including a uniform 100-foot anhydrite break, is 930 feet and is present in the area south of the potash mines. In the central part of the Delaware basin the succession is represented by banded anhydrite and white anhydrite. Adjacent to the reef in the east part of the basin, this succession contains interbedded halite.

Lower Castile time was a period of predominant anhydrite deposition and was followed by a period of predominant halite deposition. This depositional change marks the close of lower Castile time and the start of upper Castile. The lower Castile formation is approximately 2,000 feet thick on the south end of Delaware basin and progressively thins northward to 1,300 feet in the area adjacent to the

[8] J. A. Udden, "Laminated Anhydrite in Texas," *Bull. Geol. Soc. America*, Vol. 35 (June, 1924), pp. 347–54.

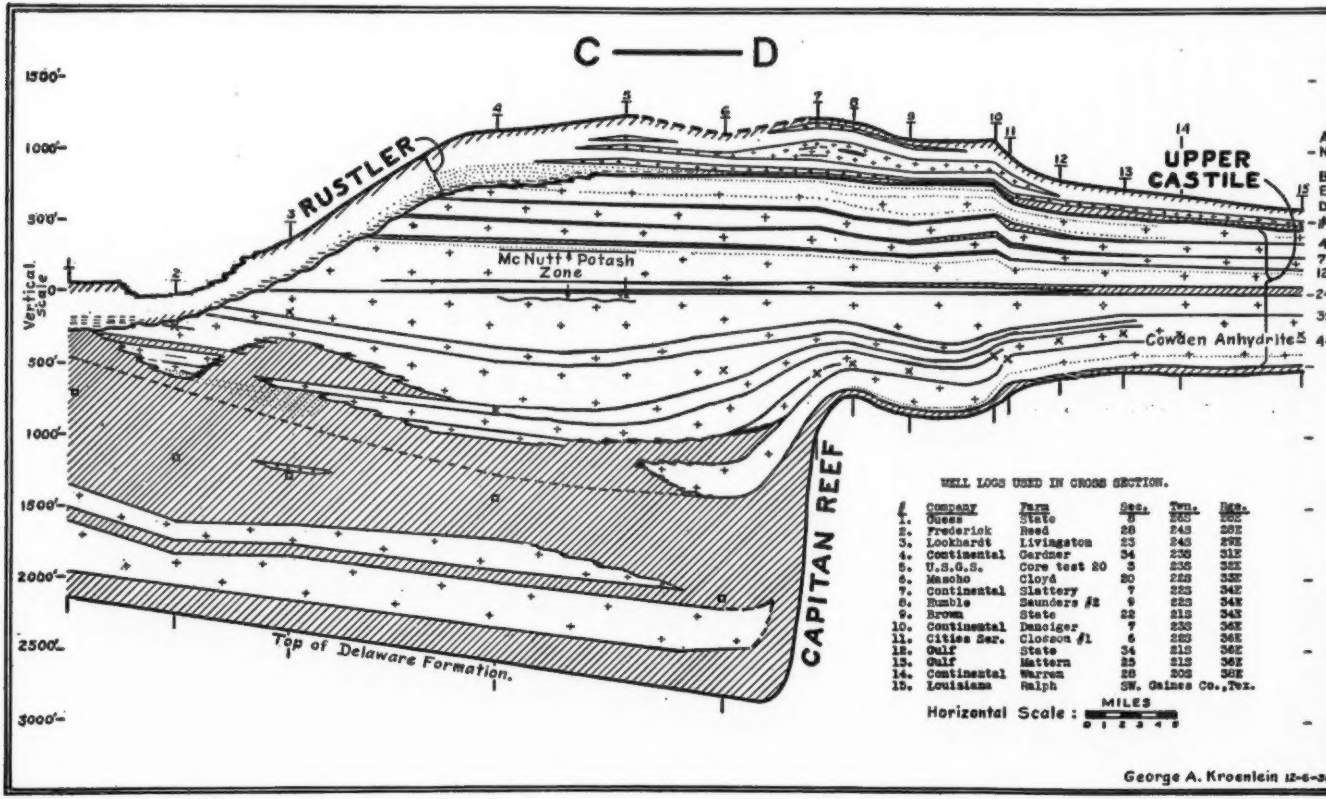

FIG. 3.—West-east cross section *CD*. Location shown on Figure 1.

reef. A north-south series of test wells located just east of the Pecos River contain marginal basin deposits of red clay, sand, and calcareous anhydrite in the zone above the lower Castile. These deposits indicate that the west shore line of the upper Castile lake was located here and that the shore line had migrated eastward from its original position on the west side of Delaware basin. This migration was caused by eastward tilting of the west part of Delaware basin. This tilting was contemporaneous with the change in deposition, and it is thought that the movement choked off the supply of marine water necessary for predominant anhydrite deposition.

UPPER CASTILE: STRATIGRAPHY AND HISTORY

The eastward tilting of the Delaware basin caused Delaware Lake to spread eastward across the reef, joining numerous small post-Capitan lakes. In the Delaware basin, the west shore line of this lake was located approximately along the line on Figure 1 which indicates subsurface extent of the upper Castile evaporite. The deep part of the upper Castile basin was within the Delaware basin and its floor was approximately 700 feet below the top of the reef. Terrestrial waters emptying into the lake on the south and west margins deposited great sheet lenses of anhydrite and lesser amounts of red shale, sand, and dolomitic anhydrite. In the Delaware basin, it is impossible to determine a stratigraphic break between the lower and upper Castile because of the previously mentioned anhydrite lenses. A dashed line approximating an arbitrary base of upper Castile in the Delaware basin is drawn on both cross sections. Outside the Delaware basin the upper Castile appears to be conformable on the Tansill[4] member of the Capitan formation. The thickness and extent of the upper Castile outside the Delaware basin is shown on Figure 1 by isopach lines. The maximum thickness in Delaware basin is approximately 2,400 feet.

The name "Salado"[5] has been proposed for the upper part of the Castile formation. A division was made in the Castile formation based on a potash content of more than 1 per cent K_2O equivalent. Well No. 10 of cross section *AB* is used to define the base of the Salado which is placed at the heavy *X* between Anhydrite beds No. 24 and

[4] Name proposed by DeFord, Riggs, and Wills in a forthcoming paper.

[5] W. B. Lang, "Upper Permian Formation of Delaware Basin of Texas and New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19 (1935), pp. 262–70.

Lang purposes to revise his description of the Salado halite to make it the same as the upper Castile of Kroenlein and others. Walter B. Lang, "Salado Formation of the Permian Basin," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 10 (October, 1939), pp. 1569–72.

No. 39. The base of the Salado is approximately 1,000 feet above the arbitrary base of upper Castile. There is 2,640 feet of Castile below the Salado in this well. A general division of the Castile formation based on unit potash content can not be made because a unit of potash occurs lower in the evaporite section along the shallow margin of the basin than in the deep part of the basin.

Halite is the main constituent of the upper Castile, whereas anhydrite is the main constituent of the lower Castile. The sequence of halite is broken by uniform thin beds of anhydrite with remarkable regional extent. These anhydrite beds are numbered on the right side of the two cross sections from youngest to oldest, as follows: No. 4, No. 7, No. 12, No. 24, No. 39, and No. 44.

An interesting phase of deposition is that each anhydrite bed has an inch-thick bed of gray-green clay at its base. This clay bed is not apparent in well cuttings, but is always present in cores.

Considerable red, green, and gray clay is present as disseminated inclusions and beds. Some beds of halite contain disseminated inclusions or blebs of anhydrite. In the upper part of the upper Castile thin beds of red sand have regional extent.

Pre-potash deposition.—A bed which is a notable regional marker is present approximately 30–50 feet above the base of the upper Castile in the area east of the reef. This marker is composed of red sand disseminated through approximately 5 feet of halite. It can not be traced westward beyond the reef into the Delaware basin.

Above a basal 150-foot halite zone is a 200-foot zone of alternating halite and anhydrite beds (Nos. 39–44). The halite beds contain considerable disseminated anhydrite. At the base of this zone is the Cowden anhydrite[6] (No. 44). Zone 39–44 increases in thickness very rapidly after passing into the Delaware basin (Fig. 3). Southward the anhydrite beds in this zone increase in thickness at the expense of the halite beds, and the entire zone becomes a thick bed of anhydrite as the south end of the Delaware basin is approached.

When the southeast-northwest trending shore line on the west side of the upper Castile Lake is reached this solid anhydrite zone overlaps on the Tansill member of the Capitan formation in south Ward County, Texas, and on the lower Castile in southeast Eddy County, New Mexico.

The first indication of potash in the Delaware basin appears above the Cowden anhydrite (No. 44). It is the comparatively insoluble mineral polyhalite, associated in deposition with anhydrite. Poly-

[6] Named by Giesey and Fulk, "North Cowden Field, Ector County, Texas," a forthcoming paper.

halite occurs in the lowest part of Zone 39–44 along the east margin of the basin, and its stratigraphic occurrence is progressively higher in the section as the low part of the basin is approached.

Halite bed 24–39 is the thickest in the upper Castile and contains a commercial bed of potash at its top. This halite member has its maximum development of 500 feet in a crescent-shaped area in the east and north part of the Delaware basin. Several very thin polyhalite beds are present in the halite. Evaporation without additional water inflow progressively decreased the area of deposition during 24–39 time, until it was confined to the Ochoa basin (Fig. 1). At this stage the concentration of potassium was high and near saturation. Commercial beds of potash were deposited under the favorable conditions existing in shallow lagoons around the margin of Ochoa Lake.

Deposition of soluble potash.—The problem of potash deposition is complex and although many data have been accumulated by German scientists, a satisfactory solution has not been presented. Many chemists have evaporated sea water and studied the sequence of evaporite deposition. The predominant soluble potash mineral thus obtained is carnallite. However, the Spanish Cardona, the French Alsace, the Russian Perm, and the American Carlsbad deposits all contain sylvite deposited in the first cycle of deposition and carnallite in a later cycle. Therefore, it is apparent that the chemical content of the potash depositing solution is different from that of the ocean. Thus far efforts to reproduce in a laboratory the chemical and physical conditions present in natural basins undergoing evaporite deposition have proved ineffective.

Common potassium minerals are divided into two classes based on their relative solubility in water. Sylvite (KCl) and carnallite ($KCl \cdot MgCl_2 \cdot 6H_2O$) are the most soluble; langbeinite ($K_2SO_4 \cdot 2MgSO_4$) and polyhalite ($CaSO_4 \cdot MgSO_4 \cdot K_2SO_4 \cdot 2H_2O$) are relatively insoluble. Deposits of sylvite, carnallite, langbeinite, and rare potassium minerals are confined to restricted areas. Polyhalite has the greatest regional distribution, but its close association with anhydrite, its low potash content, and relative insolubility in water prevent commercial exploitation. The run of mine potash rock is composed of a mixture of sylvite (43 per cent), halite (56 per cent), and a small amount of green clay. Schaller and Henderson[7] give a thorough description of the various potash minerals found in New Mexico.

Because sylvite and carnallite are very soluble, their occurrence in ordinary drill cuttings is rare. However, certain features in the

[7] W. T. Schaller and E. P. Henderson, "Mineralogy of Drill Cores from the Potash Field of New Mexico and Texas," *U. S. Geol. Survey Bull. 833* (1932).

samples indicate the presence of soluble potassium minerals. Bright carmine discoloration is an indication of their possible presence. Angular pits in the halite particles, indicative of the high solubility of some original constituent of the sample, are caused by the dissolving out of the soluble potassium minerals from the halite matrix. A sure indication is the presence of blue halite. Wherever sylvite is found, blue halite is associated with it.

The deposit of the United States Potash Company (the south mine indicated on Fig. 1) is representative. Because the deposit is undisturbed and flat-lying and has a uniformly high potash content and purity, it ranks among the best in the world. Deposition took place in a shallow lagoon on the northwest margin of Ochoa basin. This lagoon was approximately 75 feet deep and is defined by a structural map of Anhydrite No. 24. Permission to publish the data from the twenty odd core holes defining this lagoon has not been secured. The axis runs northeast-southwest for 8 miles; the lagoon had a width of 4 miles.

In this deposit eleven beds of soluble potash[8] are present in a zone 250 feet thick. This is called the McNutt zone and was first detailed in the potash core test drilled by the Snowden-McSweeney group on the V. H. McNutt potash permit (well No. 5, Fig. 2). V. H. McNutt was the father of the first commercial development of Permian potash in the United States.

The potash beds of the McNutt zone are separated by beds of halite, which contain disseminated inclusions and very thin beds of polyhalite, anhydrite, and red and green clay. Low-grade halite rock adjacent to the potash beds contains disseminated crystals of soluble potassium minerals.

A white polyhalite-anhydrite bed 75 feet above the base of the McNutt zone is the marker bed, Anhydrite No. 24. This 4-foot bed of polyhalite is white, a notable departure from the usual red. Four of the eleven beds of potash in the McNutt zone are found below the marker bed, and seven above.

The four beds below the marker have sufficient potassium content and thickness to be minable. Of these, the bottom bed is richest and most uniform; its average thickness is approximately 9 feet, and it occupies an area of more than 1,500 acres.

Of the seven beds above Anhydrite No. 24, the lower three contain sylvite, and the upper four a mixture of sylvite and carnallite.

[8] A "bed of potash" is a mixture of halite, clay, potassium minerals, and minor impurities, several feet thick, containing 5 per cent K_2O equivalent or more in soluble form.

Each successively younger bed of potash in the McNutt zone has an increased clay content. Each younger bed of the four minable beds covers a progressively larger area on the floor of the lagoon. A barren core test on the west edge of the deposit contains two beds of sand equivalent to the basal bed of potash. This sand probably represents dunes at the margin of the lagoon.

Other deposits of commercial importance have been discovered by core-hole exploration. The Potash Company of America mine is not in the Delaware basin but in a low on the back or north side of the reef. Another deposit lies directly above the reef in a low developed by irregular reef topography. Still another deposit was formed in a small lagoon south of the United States Potash mine on the west margin of the Ochoa basin. Some other deposits are without sufficient core-hole development for commercial classification.

The occurrence of langbeinite immediately below Anhydrite No. 24 is different in each deposit. It is absent in some deposits and occurs alone or mixed with sylvite in others. In one area two beds of carnallite are found at the top of the McNutt zone above the eleven beds mentioned previously. In each deposit the composition of the beds in the McNutt zone is different. This is evidence in support of the theory that each deposit was laid down in an individual shallow lagoon on the margin of the Ochoa basin.

Other favorable areas for commercial potash deposits are present along the margin of the Ochoa basin. The United States has no cause to fear a shortage of potash in the near future, because of the large known reserve and the immense unexplored favorable area present.

Above Anhydrite No. 24 the upper Castile contains three widespread anhydrite beds each about 20–30 feet thick, No. 12, No. 7, and No. 4. Considerable red clay is present as disseminated inclusions and in beds. Much polyhalite is associated with anhydrite beds in the shallow parts of the basin. Locally thick beds of low-grade carnallite occur above Anhydrite No. 4 and are associated with red clay.

Eastward tilting of the Delaware basin closed Castile time. All the area west of the approximate location of cross section *AB* (Fig. 1) was raised above the brine level and subjected to erosion by inflowing terrestrial waters.

RUSTLER FORMATION

In the deep part of the Delaware basin there appears to be no break in deposition between the upper Castile and the Rustler, but the Rustler laps across underlying beds as the margin of the basin is approached.

The main constituent of the Rustler formation is anhydrite with lesser amounts of gray and red clay, red sand, dolomite, and halite.

The presence of considerable halite, shown between wells No. 4 and No. 12 on cross section *CD* (Fig. 3), indicates that the deep part of the basin in Rustler time was in approximately the same area as earlier occupied by the Ochoa basin. In this locality the Rustler is approximately 450 feet thick; it thins north, east, and west. Southward it thickens. Two shaly dolomite zones that are present in the upper part of the formation become oölitic toward the south.

The Rustler evaporite period was closed by clastic deposition resulting from the invasion of terrestrial waters carrying fine red sand and silt.

HISTORICAL SUMMARY

After the death of Capitan reef, a period of evaporite deposition started in the Delaware basin. Anhydrite was the predominant evaporite. Uplift of the west part of the Delaware basin closed lower Castile time and halite became the dominant evaporite. Evaporation exceeded run-off sufficiently to bring about conditions favorable to soluble potash deposition. Increased run-off stopped potash deposition and more halite was deposited. Upper Castile time was brought to a close by uplift of the west part of the Delaware basin and predominant anhydrite deposition started. The Rustler formation was deposited from run-off containing a large amount of red silt, sand, and some lime. This period was closed by terrestrial flooding containing much fine red sand and silt.

DISCUSSION

E. Russell Lloyd, Midland, Texas.—Mr. Kroenlein's interpretation of the demise of the Capitan reef is interesting and logical, but I prefer an alternative explanation involving a general positive movement of the whole of the Permian basin. It will be pretty generally agreed that during middle Delaware Mountain and upper Delaware Mountain (Capitan) time the Delaware basin was connected with the open ocean on the south by a channel not necessarily wide but sufficiently deep to permit a free circulation of normal or nearly normal water throughout the Delaware basin. At the close of Capitan time this free circulation was stopped, as is evidenced by anhydrite in the Delaware basin in the overlying Castile formation. In my opinion the simplest explanation for this is the theory that a general uplift of the whole area relative to sea-level brought the reef and the backreef or lagoonal area above sea-level and brought the channel connecting the Delaware basin with the open sea sufficiently near sea-level that new reefs were developed, cutting off the free interchange of marine water with the waters of the Delaware basin. This regional uplift at the close of Delaware Mountain (Capitan) time marks the beginning of a new stage in the evolution of the Permian basin. The Delaware basin itself was not elevated above sea-level but probably remained as a fairly deep lagoonal basin. The banded anhydrite and the purity of the salt in the lower Castile may be evidence of deposition in fairly deep water.

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SUBSURFACE CROSS SECTION OF PERMIAN FROM TEXAS TO NEBRASKA[1]

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ABSTRACT

The regional correlations of the lower and middle Permian are illustrated by means of sample logs of twenty wells situated nearly in a straight line from southeastern Irion County, Texas, to Phelps County, Nebraska. Two major disconformities, one at the base of the Wolfcamp and the other at the base of the Leonard, are traceable the entire distance. The lower of the two disconformities lies just under the lowest occurrence of the genus *Schwagerina* as recently redefined by Dunbar and Skinner and is correlated by the writer with the middle of the Harpersville in central Texas, the base of the Wanette in central Oklahoma, and the base of the Admire in Kansas and Nebraska. The disconformity at the Leonard-Wolfcamp contact represents a period of erosion and a striking environmental change from marine to semi-marine and saline conditions. An interesting transition occurs in the Leonard and lower Word equivalents from marine shales and limestones in western Texas, through semi-marine fossiliferous limestones, dolomites, shales, and anhydrites in west-central Texas, to redbeds, dolomites, anhydrites, and salts in Oklahoma, Kansas, and Nebraska. The Leonard-Wolfcamp contact occurs immediately below the Elm Creek in central Texas, on top of the Wanette in central Oklahoma, and probably between the Herington and the Winfield in Kansas and Nebraska. A local disconformity at the base of the San Angelo in Texas and the base of the Cedar Hills in the more northerly wells of Kansas seems to be missing in the deeper part of the Anadarko basin.

INTRODUCTION

To the present, the greater part of the published stratigraphic work on the Permian of the Mid-Continent region has been surface geology; but for several reasons, the surface picture is incomplete and unsatisfactory. Good exposures are relatively scarce and represent only a small part of the general area of Permian outcrops. The surface beds are largely non-fossiliferous red shales, and they commonly contain sandstones and conglomerates of local extent which lead to confusion in the study of regional unconformities and disconformities.

Complete samples of hundreds of well sections are now available for study in areas farther basinward, where the sediments are thicker, more completely represented, more fossiliferous, and less complicated by shallow-water conditions. It is evident that a much more complete and satisfactory conception of the Permian may be acquired from well data than from outcrops. The Indian Territory Illuminating Oil Company has kindly consented to the publication of the subsurface data of a limited number of wells, in order that the writer might contribute some of his ideas on Permian stratigraphy to the general fund of public information.

[1] Read before the Association at Oklahoma City, March 22, 1939. Manuscript received, June 5, 1939.

[2] 4301 Locke Avenue. Formerly research geologist, Indian Territory Illuminating Oil Company.

It is the purpose of this paper to present the regional stratigraphy of the "Blaine"[3] and older Permian beds. The picture is expressed in terms of local nomenclature now in use in each of the various states and districts represented, and such names have been chosen as seem most convenient in illustrating the correlations. Although every effort has been made to maintain accuracy in the use of local names, a critical analysis of the details of the cross section may reveal some discrepancies, and it may become evident that better names could have been chosen. If such discrepancies and departures from current use are found, it should be understood that the writer is not attempting to introduce changes in the usage or scope of the local nomenclature or to perpetuate the use of certain names which may be unpopular or inappropriate. It will be seen that many names now in use in the various localities represented by the cross section do not fit the writer's interpretations; but he feels that, until there is more general agreement among geologists regarding the details of the stratigraphy, the introduction of new and revised nomenclature would be premature.

Twenty wells, of which samples are available, have been selected for a cross section from Texas to Nebraska. The locations of the wells are shown on the index map (Fig. 1). The complicated and disputed subsurface conditions of the Permian basin farther west are largely avoided, in order to obtain the simplest possible picture that will illustrate the relationship of the Mid-Continent Permian to the more truly marine section on the south. The cross section does not extend to the surface, but the supposed surface correlations and the nomenclature are discussed. The marine Permian section of the Glass Mountains, 150 miles southwest of the south end of the cross section, is used as a standard for reference.

The main regional structural features traversed by the cross section are the so-called "Black Shale basin" of western Texas, the west flank of the Bend arch, the Electra arch, the Red River syncline, the Wichita Mountain uplift, the Anadarko basin, the Barton arch, and the Salina basin.

The principal stratigraphic divisions of the Permian represented in the cross section are the Wolfcamp, the Leonard, and the lower part of the Word of the Glass Mountain section. The upper Permian formations, including the Delaware Mountain (or upper Word) and Capitan, are present in wells farther west, but are believed by the

[3] Equivalents of the type Blaine gypsum, Dog Creek shale, and Chickasha shale of Oklahoma have been loosely referred to in Texas as the "Blaine" or as the "Blaine of Texas."

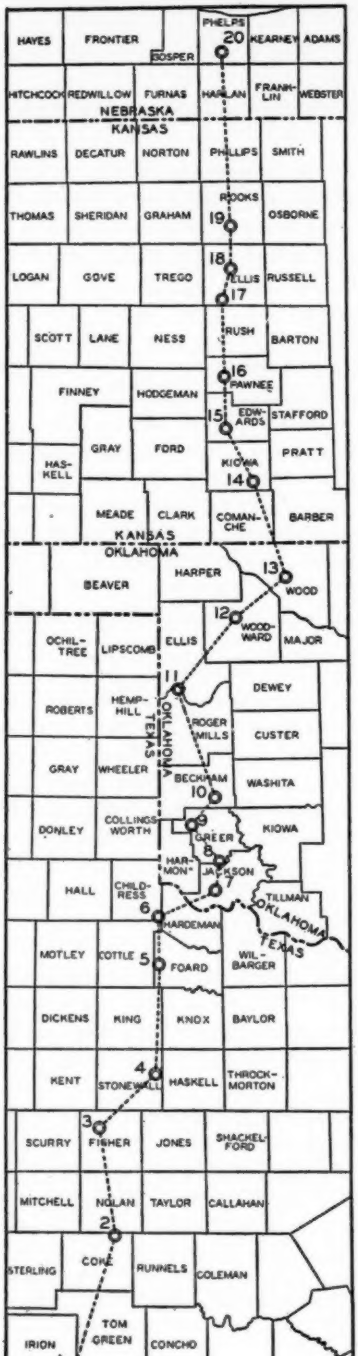


FIG. 1.—Index map of parts of Texas, Oklahoma, Kansas, and Nebraska, showing location of geologic sections (Figs. 2 and 3).

writer to be absent from the wells chosen, except well No. 1, in which the upper Word is possibly represented. The Custer group[4] appears in a few wells, but no attempt is made to show its regional features.

PALEONTOLOGY

The correlations here used are, in a broad way, based on paleontology. Ammonites and fusulines furnish what is perhaps the most reliable published paleontology for correlation purposes in the Pennsylvanian and Permian. The general surface correlations are now quite well established by fossil evidence. Although identifiable ammonites are rare in well cuttings, fusulines are abundant at some horizons and sufficiently well preserved for accurate identification.

The writer is indebted to Robert Roth, formerly with the Indian Territory Illuminating Oil Company, for the first dependable paleontology derived from well cuttings which established the correlations of the Permian from the surface to the subsurface. In 1931, Roth recognized the fusuline faunas of the Wolfcamp, the Leonard, and the lower Word in wells of Schleicher and Irion counties in Texas and later carried the correlations from these wells to the Stanolind Oil and Gas Company's Williams No. 1, which is the most southerly well in the cross section. He also recognized the Wolfcamp fauna in wells in central Texas, Oklahoma, and Kansas. This information furnished the writer with the broad general pattern of the subsurface stratigraphy from which the present cross section was developed.

The general scheme of the cross section has been checked by reference to the published paleontology of many authors, and most of the inconsistencies have been reconciled. There still exists, however, a wide variety of opinion among subsurface geologists as to the principles of stratigraphy, nomenclature, and general geology of the Mid-Continent Permian. For instance, there are several possible interpretations as to the age and correlation of the youngest Permian section in the Stanolind, Williams No. 1 (well No. 1). The writer favors an interpretation based on his own lithologic studies of well samples and outcrop sections and on paleontologic studies by Roth whereby the sandy section from 1,125 to 1,805 feet is correlated with the basal Word of the Glass Mountains and through numerous wells in Irion, Tom Green, Sterling, and Coke counties with the San Angelo sandstone of the outcrop, and the overlying fossiliferous limestone and shale section is correlated with the so-called "Blaine of Texas." According to the other explanation, which has recently been favored by paleontologists, the sandy zone of the Stanolind well is thought to

[4] Robert Roth, "Evidence Indicating the Limits of the Triassic in Kansas, Oklahoma, and Texas," *Jour. Geol.*, Vol. 40, No. 8 (1932), pp. 688–725.

contain a fauna which is younger than that of the "Blaine" and is presumed to be separated from the "Blaine" by an obscure unconformity.

It is now evident that there are several separate and distinct faunas which pertain to the correlation and classification of the Permian both in wells and on the outcrops. These faunas may be designated in ascending order as the Shawnee (or Graham), Wabaunsee (or Thrifty), Wolfcamp, Leonard, lower Word, upper Word, Capitan, Custer (of supposed Permian age), and Moenkopi (of known Lower Triassic age). Most of these faunal zones are bounded by regional disconformities which are fundamental in the scheme of the present cross section.

The section is sufficiently rich in fusulines to permit the correlation of the Graham of Texas with the Shawnee of Oklahoma, Kansas, and Nebraska; the Thrifty and lower Harpersville with the Wabaunsee; the Wolfcamp of the Glass Mountains with the upper Cisco and lower Wichita of central Texas, the Wanette[5] of Oklahoma, and the Admire, Council Grove, and Chase of Kansas and Nebraska; the Leonard of the Glass Mountains with a thick section of dark gray shales and thin limestones in wells of Irion County; and the Word of the Glass Mountains with the youngest marine Permian in eastern Irion County. Fusulines are not abundant enough in the arkoses of the Stratford to be of much value for subsurface correlation. No fusulines occur in the anhydrite-bearing section of the Wichita, Clearfork, San Angelo, or "Blaine" of central Texas, or in their equivalents farther north.

The fusulines of the most southerly well of the cross section (Stanolind, Williams No. 1) have been identified by John W. Skinner, with whose permission the following tabulation is herewith included.

Depth in Feet	
	WORD
1,220–1,235	*Parafusulina rothi, P. sellardsi*
3,005–3,020	*Parafusulina* fragments
	LEONARD
4,105–4,210	*Parafusulina* fragments, *Schubertella melonica*
4,495–4,500	*Schubertella melonica*
4,660–4,670	*Schubertella melonica*
4,990–5,000	*Parafusulina* sp.
5,180–5,215	*Schwagerina* sp., *Staffella lacunosa*
5,300–5,310	*Schwagerina crassitectoria*
5,350–5,370	*Schwagerina* sp., *Staffella lacunosa*
5,510–5,550	*Schwagerina crassitectoria, S. gumbeli*
5,580–5,605	*Schwagerina* sp.
5,700–5,730	*Schwagerina* sp.

[5] Darsie A. Green, "Major Divisions of the Permian in Oklahoma and Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21 (1937), pp. 1515–29.

	WOLFCAMP
5,980–5,995	*Ozawainella huecoensis*
6,485–6,525	*Schwagerina diversiformis*
	EITHER PENNSYLVANIAN CISCO OR WOLFCAMP
7,100–7,110	*Triticites* sp.
	STRAWN
7,340–7,365	*Fusulinella* sp., *Fusulina* cf. *euryteines*, *Wedekindellina* sp.
7,400–7,410	*Fusulina* sp.

On ammonite paleontology, the "Blaine of Texas" has been correlated with the upper part of the San Andres limestone of New Mexico and with the Word of the Glass Mountains.[6] No ammonites are reported from the Custer.

It seems desirable to include here a brief description of the Word formation as it is found on the south flank of Sullivan Peak in the Glass Mountains, because this locality is well known and the beds are well exposed in their normal sequence. In various other localities of the Glass Mountains, the true relationships within the Word formation are not well understood on account of changes of facies, lensing of beds, local unconformities, faulting, poor exposures, *et cetera*. The following section was measured at Sullivan Peak by Robert Roth and C. L. Mohr.

Thickness in Feet	
	CAPITAN
100	Gray massive cavernous limestone
	UPPER WORD
80	Massive sandstones with some thin gray limestones
74	Massive sandstones and thin gray limestones
225	Platy yellow sandy shale with thin blocky gray limestones in base
27	Massive sandstone with large concretions in upper part
80	Very sandy thin gray shales and gray limestones
80	Thin gray shales and limestones
84	Gray and yellow blocky limestones with interbedded yellow shales
218	Platy and blocky yellow sandy shale
868	Total thickness, upper member
	LOWER WORD
2	Gray limestone, *Parafusulina splendens*, *P. bösei*, *P. bösei* var. *attenuata*
77	Platy and blocky yellow siliceous shale, strongly resembles Leonard
37	Massive to medium-bedded dark gray limestone, *Parafusulina*, 2 sp. in base
16	Massive to medium-bedded dark gray limestone, *Parafusulina*, 2 sp.
232	Very fossiliferous dark gray limestone
2	Dark gray limestone, *Parafusulina*, 2 sp.
15	Dark gray cherty limestones, *Parafusulina*, 3 sp.
7	Platy, cherty limestone
28	Gray sandstone and dark gray platy limestone
20	Coarse conglomeratic sandstone
436	Total thickness, lower member
	LEONARD
40	Yellow platy calcareous shale and gray limestone

[6] F. B. Plummer and Gayle Scott, "Upper Paleozoic Ammonites in Texas," *Univ. Texas Bull. 3701*, Vol. III (1937), pp. 85–86, 317–19, 396–98.

The Word formation at Sullivan Peak is capable of subdivision into an upper member 868 feet thick, predominantly sandstone with minor amounts of shale and limestone, and a lower member 436 feet thick, consisting mainly of limestone and shale with conglomeratic sandstone at the bottom. Presumably, an unconformity separates the upper and lower members of the Word, but positive evidence of this is lacking at present. Although the well known ammonite fauna of the Word has not been found in the Sullivan Peak section, it occurs near the middle of the Word a few miles farther northeast at Road and Gilliland canyons. Authentic information is lacking as to whether the ammonite zone falls in the upper or the lower member of the Sullivan Peak section, or whether its equivalent is entirely missing at this locality.

Basing his opinion on published paleontology by Robert E. King,[7] Plummer and Scott,[8] Dunbar and Skinner,[9] and others, as well as on unpublished work by several well qualified paleontologists, the writer believes that the upper member of the Word at Sullivan Peak is equivalent to beds elsewhere in the Glass Mountains which carry a Delaware Mountain fauna, but that the lower member contains a distinctly older fauna which has little in common with the Delaware Mountain but is closely related to the Leonard.

The two possible interpretations as to the relation of the "Blaine" in the Mid-Kansas, Henry No. 1 (well No. 2 of the cross section) to the Glass Mountain section deserve further discussion. The correlation from the Stanolind, Williams No. 1, to the Mid-Kansas, Henry No. 1, commonly accepted by subsurface geologists before the advent of fusuline paleontology is as shown in Figure 2. It is the simplest possible correlation by the well-to-well method and requires the assumption that the fossiliferous shale and limestone section from 650 to 1,125 feet in the Stanolind well grades laterally through red, green, and gray shales with dolomitic limestones in Sterling County to similar shales interbedded with anhydrite and dolomite in the "Blaine" of Coke County. By way of Tom Green County, the sandy zone from 1,125 to 1,805 feet in the Stanolind well can be carried through numerous wells to the outcrops of the San Angelo conglomerate in and near the city of San Angelo and thence along the outcrop to localities in Coke County where it is conformably overlain by the "Blaine."

[7] Robert E. King, "The Geology of the Glass Mountains, Texas," Pt. 2, *Univ. Texas Bull. 3042* (1930), pp. 9–10.

[8] F. B. Plummer and Gayle Scott, *op. cit.*, pp. 85–86, 317–19, 396–98.

[9] Carl O. Dunbar and John W. Skinner, "Permian Fusulinidae of Texas," *Univ. Texas Bull. 3701*, Vol. 3 (1937), pp. 586, 590, 679–86, 688–89.

The other possible correlation is shown in Figure 3. It is based purely on paleontology and involves several assumptions which are justified only in the light of adequate knowledge of the ranges of the fusulines and the ammonites. Fusulines at 1,220–1,235 feet in the Stanolind well are identified as forms which are known only from the middle of the Word formation of the Glass Mountains and from the middle and lower parts of the Delaware Mountain formation of Culberson County, Texas.[10] At these two localities, the fusuline faunas are associated with ammonites, among which are several species of *Waagenoceras*.[11] The "Blaine" of Hardeman and Stonewall counties, Texas, contains two species of *Perrinites*, a genus which is known to range no higher than the Leonard in the Glass Mountains,[12] and nowhere in the world is it known to range as high as the lowest occurrence of the genus *Waagenoceras*.[13] Therefore, the fossil zone at 1,220 feet in the Stanolind well is presumed to be younger than the "Blaine." Advocates of this theory will have to demonstrate what becomes of the "Blaine" and San Angelo southward from the Mid-Kansas well. Conversely, those who hold the other theory will have to prove that the ranges of the fusulines or the ammonites, or both, are longer than some of the leading paleontologists are now willing to admit.

UNCONFORMITIES AND OVERLAPS

In the Stanolind, Williams well No. 1, the limestone at the bottom of the hole contains Strawn fossils. An unconformity occurs at 7,197 feet, and another is found at the base of the Wolfcamp at 6,750 feet. The member between 6,750 and 7,197 feet is probably upper Pennsylvanian in age. On the west flank of the Bend arch, the Wolfcamp rests disconformably on the middle and lower parts of the Harpersville formation of Wabaunsee age. In the Red River syncline, its equivalent, the Stratford member of the Pontotoc terrane rests unconformably on an abnormally thick section of the Wabaunsee. Between here and the Wichita Mountain uplift, it overlaps various horizons ranging in age from Wabaunsee to pre-Cambrian. In the Anadarko basin and northward across Kansas, the Wolfcamp equivalent rests disconformably on various beds of the Wabaunsee and locally comes very close to the Shawnee. In the Trees well in Nebraska, the age of the section just below the Wolfcamp could not be definitely

[10] Carl O. Dunbar and John W. Skinner, *op. cit.*, pp. 684–86, 688–89.

[11] F. B. Plummer and Gayle Scott, *op. cit.*, pp. 155–56.

[12] *Ibid.*, pp. 304–5, 317–20.

[13] A. K. Miller, personal communication (1939).

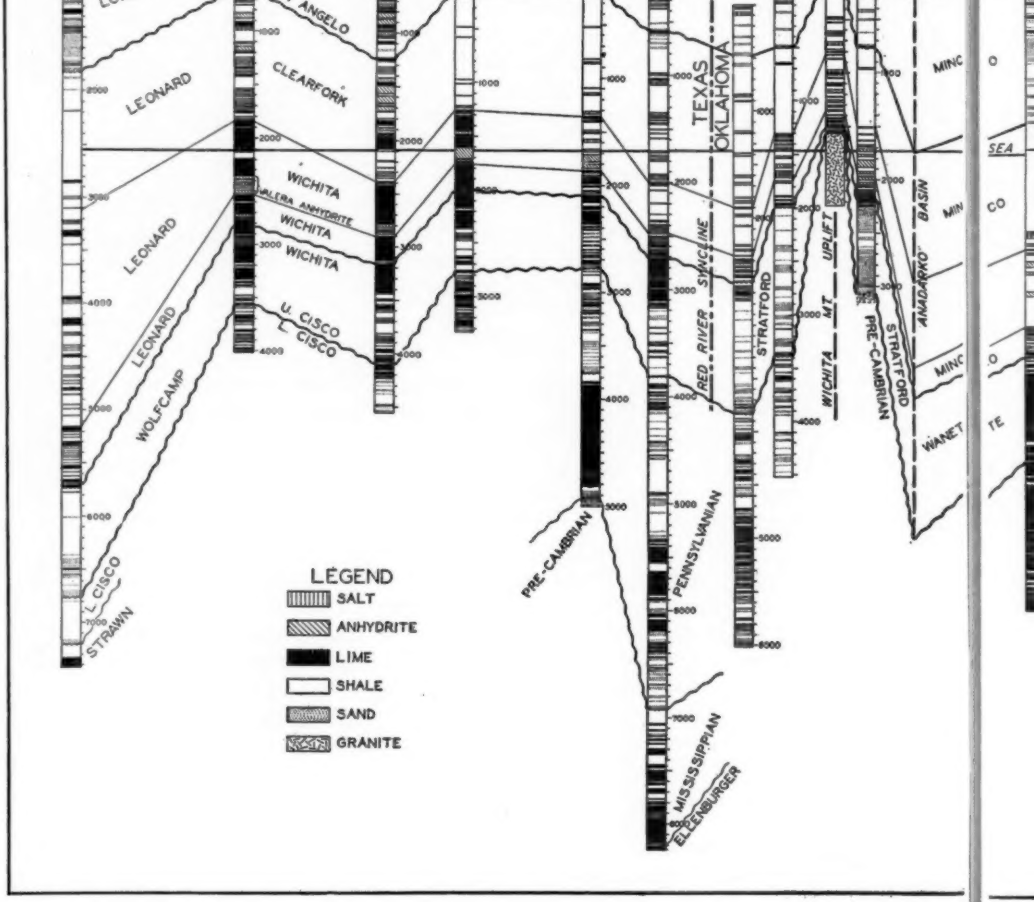
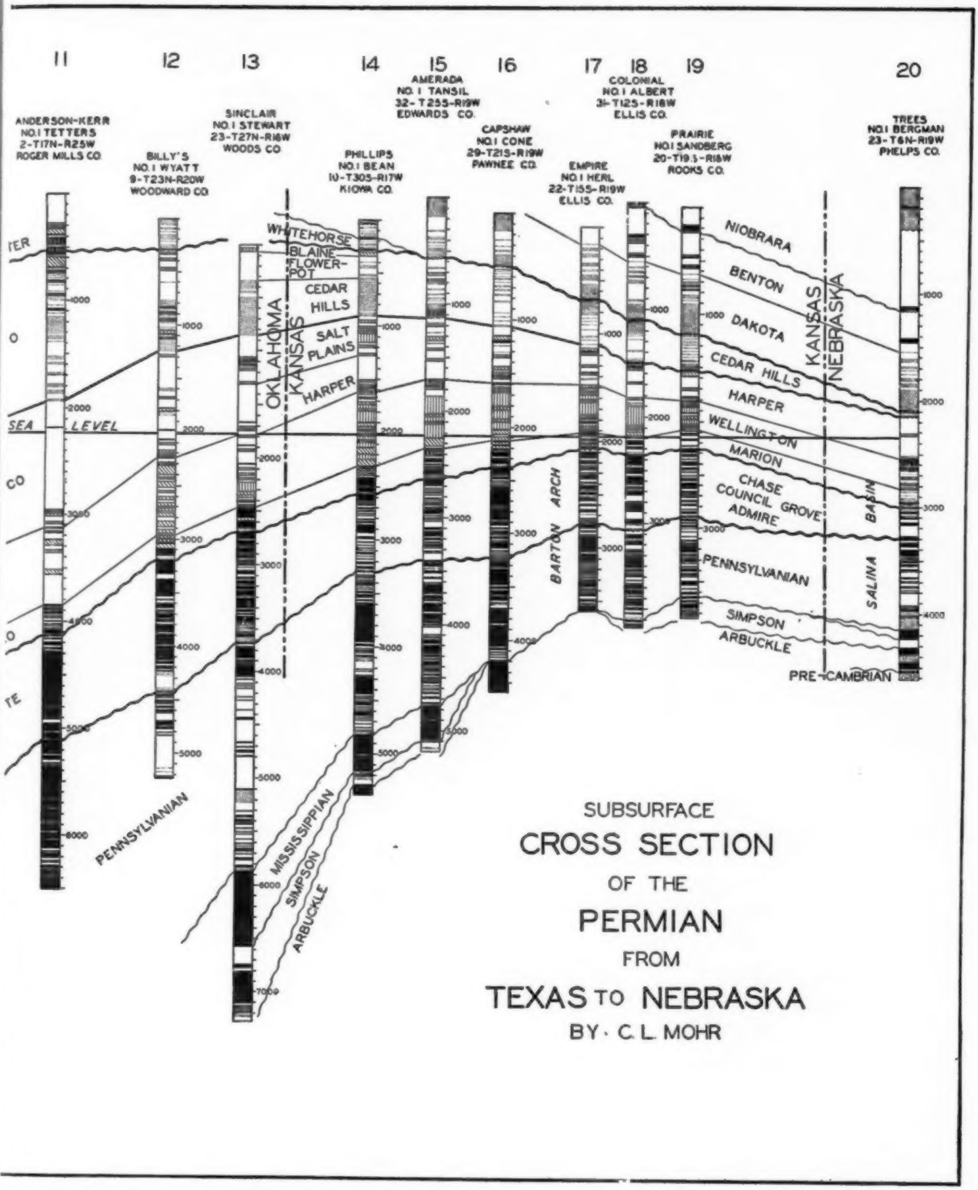


FIG. 2.—Subsurface cross section of Permi



Permian from Texas to Nebraska.

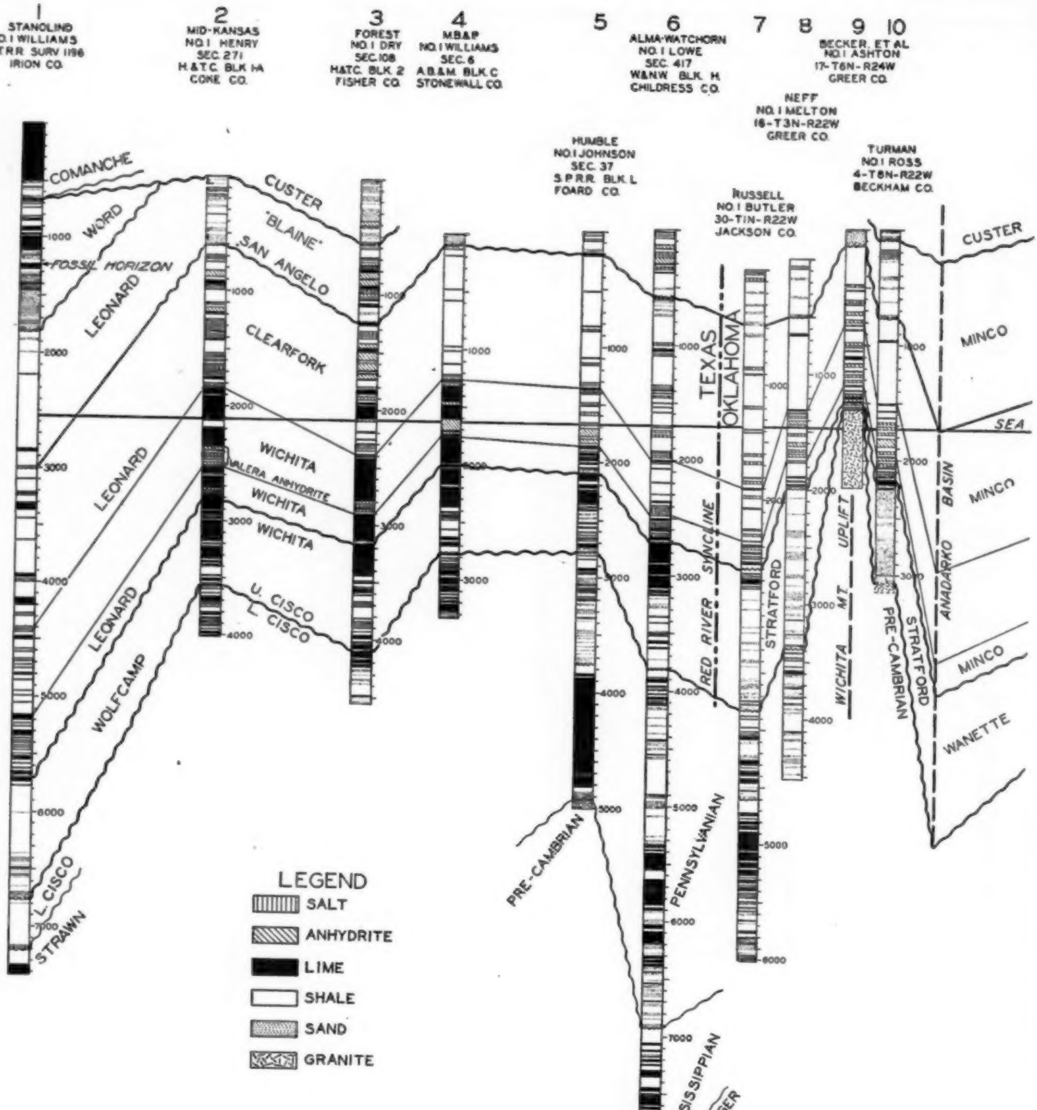


FIG. 3.—Subsurface cross section of Permian from Texas to Oklahoma.

determined, but is thought by the Nebraska Geological Survey to be Shawnee.[14]

A disconformity is found between the Wolfcamp and the Leonard on the west flank of the Bend arch, where the interval from the base of the Leonard to the top of the Coleman Junction limestone varies as much as 150 feet. Near the Wichita Mountains, the upper part of the Wolfcamp has been removed by pre-Leonard erosion. In fact, there are places where red shales of the Clearfork rest directly on the pre-Cambrian, and the Wichita, or lower portion of the Leonard, is absent by non-deposition. In the Anadarko basin and northward, the amount of overlap is slight, but there is still definite evidence of an unconformity. The angularity on this contact was first detected in core-drill work in eastern Kansas, where the interval from the Herington limestone to the Winfield limestone was found to vary from a few feet to about 50 feet.[15] The basal unconformity of the Leonard is apparently but a few feet below the base of the Herington, and varying amounts of the Odell shale have been removed by erosion.

At the base of the Word formation in the Glass Mountains, there occurs in a few localities a coarse conglomeratic sandstone with re-worked fossils and other suggestions of an unconformity. At what the writer considers to be a corresponding horizon in and near the city of San Angelo, the San Angelo formation carries similar conglomeratic sandstone. On the outcrop, the San Angelo is subject to erratic changes of thickness and character, and some 200 feet of upper Clearfork red shale between the San Angelo and the Merkel dolomite in Runnels County are missing by pre-San Angelo erosion in Stonewall County. In wells a short distance downdip from the outcrops, this unconformity is much less conspicuous. In a regional syncline in Irion County, there appears to have been continuous deposition from the Leonard into the Word. In the Red River syncline and the Anadarko basin, there are, likewise, indications of uninterrupted vertical transition. Near the Wichita Mountains and in northern Kansas, sandstones corresponding in position to the San Angelo are slightly conglomeratic and medium- to coarse-grained and contrast sharply with the underlying fine-textured sandstones and red shales, suggesting erosion and near-shore deposition. The hiatus between the Leonard and the Word would, therefore, seem small and of local extent.

[14] E. C. Reed, personal communication (1939).

[15] T. C. Hiestand, personal communication (1937).

A regional unconformity is found between the Dog Creek shale and the overlying Custer sandstones. In some wells east of the cross section, the base of the Custer rests on the basal beds of the Blaine; and there are undoubtedly localities outside the cross section where the Custer rests unconformably on the Clearfork and its equivalents.

LATERAL TRANSITIONS

Wolfcamp.—In the Stanolind, Williams No. 1, at the south end of the cross section, the Wolfcamp consists chiefly of dark gray to black shale with a few thin limestones and sandstones. On the west flank of the Bend arch, it contains light gray spicular cherty limestones in the upper part and dark gray, green, and red shales with thin dense limestones and fine- to medium-grained sandstones in the lower part. The basal sandstone is commonly medium- to coarse-grained and, in some places, conglomeratic. Near the Wichita Mountain uplift, the Stratford facies of the Wolfcamp consists chiefly of red and variegated shales, a few thin nodular limestones with a scarcity of fossils, and much arkose and conglomerate. In northern Oklahoma, the Wolfcamp equivalent is chiefly dense to granular white fossiliferous limestone with thin shale breaks in the upper three-fourths and dark gray shale and biotitic sandstone in the lower one-fourth. In Kansas, it is much the same as on the west flank of the Bend arch with spicular cherty limestones in the upper part and red and green shales in the lower part.

Leonard.—In the Stanolind well, the Leonard has a conglomeratic limestone with limestone pebbles at the base, dark gray to black shales and dark gray cherty limestones with marine fossils in the lower two-thirds, and distinctly lighter gray, green, and brown shales in the upper third. The color change near 3,120 feet from black shale below to lighter shales above is probably at approximately the same horizon as similar color changes near the Wichita-Clearfork contact in north-central Texas, and apparently can be traced across Oklahoma and Kansas.

In Coke and Fisher counties, the lower Leonard, which makes up the greater part of the Wichita formation, consists of fossiliferous marine limestones with thin shale breaks; and a 100-foot zone of anhydrite occurs about 300 feet above the base. The upper Leonard, or Clearfork, consists chiefly of red and green shales and anhydrite with some chemically precipitated dolomite. There is a transition in all of Leonard time from marine deposition south and west of the Stanolind well to saline deposition on the north.

Northward from Fisher County, the lower Leonard loses most of

its marine aspect and continues as a saline deposit of anhydrite, dolomite, and green shale with only slight changes in character nearly to the Kansas line. The upper Leonard, or Clearfork, becomes predominantly a red shale north of Fisher County and continues as such nearly to the Kansas line. A change to more concentrated saline conditions occurs in northern Oklahoma, where salt appears in the Wellington and Salt Plains formations and continues about to the Nebraska line. The Wellington salt was deposited in Oklahoma and Kansas simultaneously with the Valera anhydrite in Texas. This change represents a regional increase in salinity in Wellington time, but there is no evidence of saline conditions as far southwest as the Stanolind well, although anhydrite deposition has been noted southeast of the Stanolind well in eastern Schleicher County.

The northward transition in the Leonard from marine to saline conditions takes place very gradually and is distributed over hundreds of miles. The various types of saline deposition evidently occurred in the open sea and seem to have been practically independent of barriers.

Lower Word.—The lower Word (assuming it is equivalent to the "Blaine") is marine and fossiliferous in Irion County; and when traced through intervening wells from the Stanolind, Williams No. 1, to the Mid-Kansas, Henry No. 1, it seems to undergo a gradual transition to saline deposits. Limestones grade to dolomites and anhydrites, and the shales become more predominantly red. In Oklahoma and Kansas, very little dolomite occurs in this part of the section, and gypsum takes the place of anhydrite.

CORRELATIONS FROM SUBSURFACE TO SURFACE

In extending the section to the surface, the writer has made use of well-to-well correlations where the wells are closely spaced. Since this method is obviously unsafe in some cases, other methods of correlation have been used, chief of which are studies in distinctive lithologic characteristics of various horizons, paleontology, and the recognition of major physical breaks by the aid of lithology. The most practical method has been to identify the major physical breaks by the paleontology of the underlying and overlying beds and to determine their precise positions by lithology.

The general regional correlations and the corresponding outcrop nomenclature are shown in Table I. The nomenclature used at the south end of the cross section is based on the assumption that the fusuline paleontology of the Glass Mountains and the Stanolind well is correct. The writer feels that this assumption is entirely safe,

except for the question between lower Word and upper Word. Starting with this well and going northward, the principal horizons are correlated with the surface as follows.

TABLE I

REGIONAL CORRELATION CHART

Glass Mts.	*Central Texas*	*S. Oklahoma*	*N. Oklahoma*	*Kansas*	*Nebraska*
?	Custer	Custer	Custer	Cimarron	Spearfish
Lower Word (?) or Leonard (?)	"Blaine" San Angelo	Minco	Dog Creek Blaine Flower Pot Cedar Hills	Cimarron	Cimarron
Leonard	Clearfork Leuders Clyde Belle Plains Admiral	Minco	Salt Plains Harper Wellington Marion	Cimarron Wellington Marion	Cimarron Wellington Marion
Wolfcamp	Admiral Putnam Moran Pueblo Harpersville	Wanette	Marion Chase Council Grove Admire	Marion Chase Council Grove Admire	Marion Chase Council Grove Admire
	Harpersville Thrifty	Vanoss	Wabaunsee	Wabaunsee	Wabaunsee
	Graham	Ada Vamoosa	Pawhuska Nelagony	Shawnee Douglas	Shawnee Douglas

The unconformity at the base of the Wolfcamp is found on the outcrop in central Texas at the base of a sandstone some 50 feet below the base of the Saddle Creek limestone and above the Crystal Falls limestone. This is commonly above the middle of the Harpersville formation. Near the Wichita Mountains, this break occurs at the base of the Stratford member of the Pontotoc terrane. Farther north in Oklahoma, the base of the Wolfcamp is the base of the Wanette as defined by Darsie A. Green,[16] or the first disconformity below the Foraker limestone. In Kansas and Nebraska, it is the base of the Admire.[17]

The Wolfcamp-Leonard disconformity was determined in the Stanolind, Williams No. 1, at the base of a conglomeratic limestone

[16] Darsie A. Green, *op. cit.*, pp. 1515–29.

[17] R. C. Moore, "Stratigraphic Classification of the Pennsylvanian Rocks in Kansas," *Univ. Kansas Bull.*, Vol. 36, No. 22 (1935), pp. 13–14, 49–50.

at 5,700 feet. This contact is very difficult to identify on the surface to the northeast, but it evidently lies just below the Elm Creek limestone and above the Coleman limestone. It represents a radical change in the environmental conditions of deposition. A careful study of the distinguishing lithologic characteristics of the sediments above and below will enable one to find this contact with a fair degree of accuracy. Near the Wichita Mountains, it is the contact of the Stratford arkosic shale and the overlying Minco shale. Northward across Oklahoma, it is the disconformable contact of Green's Wanette and Minco.[18] The writer takes exception to Green's published explanation of the relationship of this contact to the Herington limestone, however, and believes that the disconformity is just below the Herington instead of above it.

The horizon designated in the cross section as the base of the Clearfork and the top of the Wichita is an abrupt color change mentioned above, which is traceable over wide areas in wells, but is not of universal occurrence on the outcrops. It is not the true contact of the Clearfork and Wichita of the outcrop (which is the top of the Leuders limestone)[19] but is the top of the Rainy dolomite about 70 feet above the top of the Leuders. This departure from the accepted outcrop classification is made in order that the nomenclature in the cross section might conform to the current usage of subsurface geologists in central Texas and the Texas Panhandle, and because the top of the Leuders seems not to be an identifiable horizon of regional extent.

BASE OF PERMIAN

Efforts of geologists in recent years to arrive at an agreement regarding an appropriate horizon at which to place the boundary of the Permian and the Pennsylvanian in the Mid-Continent region have been fruitful. In deciding upon the boundary, it is essential to consider the subsurface picture as well as the surface.

The writer believes there are several unconformities or disconformities of regional extent from which the selection might fittingly be made after a study of conditions in other parts of the world. Among these are the base of the Leonard, the base of the Wolfcamp, the base of the Wabaunsee, and the base of the Douglas. Unfortunately, there seems to be no hiatus of extremely long time value, nor one attended by general deformation and angularity, in the Mid-Continent region.

[18] Darsie A. Green, *op. cit.*, pp. 1515–29.

[19] E. H. Sellards, "The Geology of Texas," *Univ. Texas Bull. 3232*, Vol. I, Pt. I (1932), p. 174.

The overlap at the base of the Stratford adjacent to the mountains in southern Oklahoma is not due, as first appearances suggest, to extreme deformation and erosion within the time interval between the Wabaunsee and the Wolfcamp. A great part of the deformation was distributed through Pennsylvanian time, and a relatively small amount of post-Wabaunsee erosion on the Wichita Mountain uplift laid bare the older rocks down to the pre-Cambrian where the section was already greatly thinned by earlier uplifts.

The effects of regional deformation immediately preceding Wolfcamp time are, however, more conspicuous than those of other periods of movement from the Douglas to the Leonard. Conditions around the Wichita Mountain uplift furnish the outstanding example. The conglomeratic arkoses of the Stratford and the overlap of the Stratford from the Wabaunsee down to the granite are striking evidence of orogenic movement at the beginning of Wolfcamp time. For this reason, and since the paleontologic evidence, both faunal and floral, indicates a time break of sufficient magnitude for regional correlations, and since the subsurface evidence confirms the existence of such a break at all localities, it seems appropriate to extend R. C. Moore's proposed classification[20] farther southward into Oklahoma and Texas, using the base of the Admire and the base of the Wolfcamp as the base of the Permian. According to the correlations here outlined, the base of the Admire of Kansas corresponds in Oklahoma with the first disconformity below the base of the Foraker limestone, and in central Texas with the first regional disconformity below the Saddle Creek limestone, and is the first physical break below the lowest occurrence of *Schwagerina* and *Pseudoschwagerina*, as these genera are now defined by Dunbar and Skinner.[21]

DISCUSSION

E. Russell Lloyd, Midland, Texas (discussion received, July 24, 1939). I have had the privilege of reading all the papers submitted for publication pertaining to West Texas and New Mexico geology since the mid-year meeting in El Paso in September–October, 1938, and have discussed the problems and correlations of the Permian with numerous geologists in Midland and elsewhere. I believe, therefore, that I can present the opinion of a considerable group of geologists who are studying the Permian of West Texas and New Mexico.

West Texas geologists in general will agree with Mr. Mohr's correlations of the upper and lower limits of the beds of Wolfcamp age. A majority, however, correlate the beds which Mohr designates as the Custer group with part

[20] R. C. Moore, *op. cit.*, pp. 13–14, 49–50.

[21] Carl O. Dunbar and John W. Skinner, *op. cit.*, pp. 623–27, 656.

of the Delaware Mountain sandstone, lower and upper Word and Capitan being Delaware Mountain equivalents. Mohr's statement that

The Delaware Mountain (or upper Word) and Capitan are present in wells farther west but are believed by the writer to be absent from the wells chosen, except well No. 1 in which the upper Word is possibly represented,

indicates that he does not agree with our correlation of these beds.

Most West Texas geologists include the beds immediately overlying the "Blaine of Texas" in the Whitehorse group and consider the term "Custer" unnecessary.

Authors of some forthcoming papers have correlated the San Andres formation or group of New Mexico with the "Blaine of Texas" and the underlying San Angelo formation. This correlation, however, must be considered as tentative pending further work on the San Andres outcrops.

Mohr's correlation of the basal beds of the Word formation with the San Angelo will not find general acceptance inasmuch as the San Angelo and overlying "Blaine of Texas" are believed to be of Leonard age.

In a forthcoming paper M. G. Cheney recognizes the same Wolfcamp and Leonard equivalents in the outcrops on the eastern side of the Permian basin in Texas as does Mohr and uses these terms as of series rank in discussing the formations formerly included in the upper part of the Cisco, the Wichita, Clear Fork, and lower Double Mountain. The Cisco series as described by Cheney is restricted to the part of the former group below the base of the Wolfcamp. If this usage is generally accepted, as appears likely, it will in the future be incorrect to apply the term "upper Cisco" to beds of Permian age, and the Wichita group will either become obsolete or be restricted to the part included in the lower Leonard.

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GEOLOGICAL NOTES

PALEOZOIC UNDER FLORIDA?[1]

ROBERT B. CAMPBELL[2]
Tampa, Florida

Interest of geologists is again drawn to Florida by the discovery of black shale, thought to be Pennsylvanian or older, in the St. Mary's River Corporation's Bank of Hilliard No. 1 in Nassau County, a short distance from the Georgia line. The location is on a structure mapped on isolated exposures and drainage anomalies by the operator J. Eugene Brown, in 1932, and later by E. W. Brucks who reported on June 17, 1933. These reports, which were commercial in nature, described the structure as essentially a monocline, downfaulted toward the north and west. Mrs. E. R. Applin has been examining the samples and the brief paleontology herewith is taken from her reports. The boring, cable-tool, encountered Miocene rocks at 30 feet, Eocene (Ocala limestone, Jackson in age) at 500 feet, Upper Cretaceous at 2,985 feet, Tuscaloosa formation at 4,547 feet, and the black shale afore-mentioned at 4,635 feet. The bottom of the hole is now 4,762 feet where the well is shut down to cement a persistent cave.

Nothing comparable with this shale has been seen from this part of the section before. The subsurface section of northern peninsular Florida is briefly, from below upward, a basement complex, regarded by the State Geological Survey as pre-Cambrian, succeeded by Tuscaloosa, Eutaw, and Ripley-Selma beds, then by several thousand feet of Eocene limestones, the oldest exposed rocks of Florida being the Ocala limestone, Jackson in age.

Although more Cretaceous is reported from some wells south of the Ocala uplift, on the uplift, and at the north and west, nothing has hitherto been reported between the Upper Cretaceous of Florida and South Georgia, and the basement complex.

A review of the published paleogeographic maps of the area shows that W. J. Miller[3] has this area on the south shore of Appalachia during Paleozoic time, with open straits between there and Antillia. Schuchert's map[4] shows the area in question in the same relationship

[1] Manuscript received, August 24, 1939. Published by permission of Saint Mary's River Corporation.

[2] President, Peninsular Oil and Refining Company.

[3] Wm. J. Miller, *An Introduction to Historical Geology*, 4th edition (1937). D. Van Nostrand, Inc., 250 Fourth Avenue, New York.

[4] Charles Schuchert, *Historical Geology of the Antillean-Caribbean Region* (1935). John Wiley and Sons, Inc., New York.

during middle Pennsylvanian. Bailey Willis[5] shows this area land in Lower Cambrian; land or sea, more likely land, in Middle and Upper Cambrian; the same in Ordovician and Silurian; in the Devonian, land; Mississippian, land or sea, more likely land; Pennsylvanian, land; and in the latest Paleozoic still land but close to shore of a "land or sea, more likely land" area.

Grabau's[6] paleogeographic maps show the area to be land during the Paleozoic but, contrary to the Miller and Willis maps, the area is always near the western shore of Appalachia. Scott[7] in his maps of the successive periods groups his land areas with "unknown" but with reference to the seas shows the following of the Nassau County, midway between Atlantic and inland sea areas: Devonian, on shore of sea south of land area; lower Carboniferous, slightly farther in sea than in Devonian; upper Carboniferous, emerged again from the sea.

This review of the literature at hand is not, of course, to determine the age of these black shales, but rather to discover if there was any insurmountable barrier to a tentative assignment of these rocks to the Mississippian because of their similarity to the Chattanooga shales. At any rate such a suggestion is here made, not as a definite determination but as a point of departure for the inevitable debate bound to be precipitated by this discovery.

The subject is, of course, of interest to all geologists but of particular interest to petroleum geologists working in the southeastern states and the makers of paleogeographic maps, both of whom are occupied with the subject of Florida's subsurface, a matter that has managed to remain in dispute since the day of the first boring in the state. A complete set of samples has been deposited with the State geologist for the benefit of other operators and the public.

[5] Bailey Willis and Rollin D. Salisbury, *Outline of Geological History with Special Reference to North America* (1910). University of Chicago Press. Paleogeographic maps were prepared by Bailey Willis.

[6] Amadeus W. Grabau, *Textbook of Geology* (1921). D. C. Heath, New York.

[7] William B. Scott, *An Introduction to Geology*, 2d edition (1907). The Macmillan Company, New York.

DEEP TEST IN FLORIDA EVERGLADES[1]

ROBERT B. CAMPBELL[2]
Tampa, Florida

On May 21, 1939, the Peninsular Oil and Refining Company (Florida) abandoned its deep test in the Florida Everglades in what is apparently the equivalent of the Fredericksburg of Texas at a depth

[1] Manuscript received, August 29, 1939.

[2] President, Peninsular Oil and Refining Company.

of 10,006 feet. The well was spudded on New Years Day, 1939, Loffland Brothers of Tulsa being the contractors. Robert B. Campbell was in general charge of the operations and Mrs. E. R. Applin was retained to examine the cuttings and cores.

Transportation was along the Tamiami Trail to a point 50 miles west of Miami, thence south through the glades, more than 2 miles being over a plank road. The chief difficulty in drilling was lack of mud. Strange as it may seem, the Florida Everglades contain no mud, at least no mud suitable for drilling purposes. As the hole itself made none, all mud used in the drilling of this well (brands specially prepared for oil-field operations) had to be imported.

The well commenced in hard limestone of the Caloosahatchee formation (Pliocene) and penetrated white cream-colored limestone to about 110 feet where the material changed to light gray coarse quartz sand, containing a few shell fragments. This continued to 390 feet which point has been determined as the top of the Miocene. After about another hundred feet of sand and fragments of shells the bit went into a series of limestone, dolomite, and anhydrite, which continued to the bottom of the hole. Further points in the paleontology are: top of Oligocene at 900 feet; top of Eocene (Ocala limestone), 1,220 feet; top of Upper Cretaceous (*Lepidorbitoides*), 5,730 feet; top of Lower Cretaceous (miliolid), 8,106 feet. In both Lower Eocene and Lower Cretaceous anhydrite made up a large part of the section. The occurrence of the Lower Cretaceous in the subsurface of Florida, though here published for the first time, was no surprise to the operators as Mrs. Applin had noted it several years ago from another well in the state, an occurrence that could not be announced because of commercial commitments.

The entire section was very porous, causing continuous loss of circulation, three pronounced caverns being encountered at 2,846–2,864, 2,958–2,963, and 2,986–2,997 feet. Drilling continued to 3,250 feet but finally 11$\frac{3}{4}$-inch casing had to be set, which was cemented at 3,089 feet. After this new start, circulation was improved but was lost in increasing quantities as the drilling proceeded until near 6,000 feet returns were lost entirely. From here on, the drilling proceeded with clear water. Circulation could be started by putting in more of the precious mud but it would continue only for a short while. From 8,500 feet to the bottom, drilling proceeded with clear water and no further returns. Samples taken from the last 2,000 feet consisted of cores taken about 100 feet apart. Though laboratory tests with solvents developed some oil stains, no showings of oil or gas were seen at the well, and, the electric coring device showing nothing to the contrary, the well was plugged and abandoned.

SUGGESTIONS FOR ORGANIZATION OF STUDY GROUPS[1]

CARLETON D. SPEED, JR.[2]
Houston, Texas

Due to numerous inquiries, both oral and written, as to how the Houston Geological Society Study Groups were organized, this short note is offered in the hope that it may be of some help to other local geological societies.

The officers and executive committee of the Houston Geological Society met and discussed the need for studies of problems faced daily by its members. It was further decided that the summaries should be published in mimeograph form and quickly distributed in order that the members could place the summaries in a notebook that they could refer to from day to day. The group also realized that such summaries should be revised at frequent intervals in order to keep abreast of new developments. Any other societies contemplating the organization of similar study groups should first decide the problems most vital to the active members within its membership. These problems should then be listed on a penny postal card and mailed to the members, with space left to check in the order of their importance the problems that the individual member is most interested in. The cards should then be returned to the responsible person and these should in turn be placed before the general committee. It is the duty of the committee to group the cards as to first, second, and third choice of subjects and select the leader for the individual groups, which average six to eight men. The leader should be selected for his ability to keep the group meeting regularly, its members interested, and in general oversee the job of getting summarized facts that may be published for the good of the entire membership. The briefs should be edited by persons thoroughly familiar with the subject and after being proofread the general brief should then be passed to the secretary-treasurer or to the person responsible for publishing the individual briefs.

In the case of the Houston society it was found convenient to meet 3 hours each Saturday morning in one group, and in other groups the members met 3 hours on a Tuesday, Wednesday, or Thursday night. The various groups met in company offices, the public library, or in a member's home. When meeting in a Study-Group member's home it was agreed that no food or drink was to be served in order that the member would not feel obligated to entertain his guests. Invariably it was found that considerable time and thought had to be given to

[1] Manuscript received, August 25, 1939.

[2] Secretary and treasurer, Houston Geological Society, Second National Bank Building.

related subjects in order properly to attack the specific subject under study. It is the consensus that intimate discussion of the subject preliminary to the writing of the brief stimulates the thinking processes of the member and actually causes him to increase his own personal interest in the subject tremendously. Experience of the average member has taught him that members benefit approximately in proportion to the amount of study given the subject. In many cases the best results come from trial-and-error methods used in actual every-day application that it is not possible to get anywhere else. It is the plan of the Houston Geological Society eventually to consolidate the permeability, porosity, and connate-water groups in one large evaluation group.

From experience it seems advisable to charge enough money for the series of publications to cover cost of printing, cost of stationery, and cost of mailing. In the case of the Houston Geological Society the only cost has been the printing and mailing as all officers and members contributed their time and efforts free.

Any specific problems confronting a society should be added to the list or, in the event the society is not sufficiently interested or large enough, any of the subjects listed may be omitted. It is possible for a local society to pool its information in regional studies and by hard work and coöperation secure results that the average company budget of time and money will not permit. Suggested subjects are here listed.

- Surface geology
- Subsurface geology
- Paleontology
- Stratigraphy
- Sedimentation
- Paleogeography
- Exploitation geology
- Aerial geology (photographs)
- Soil analyses
- Geophysics
- Structural geology
- Mechanical well surveying
- Evaluation
- Statistics
- Economics
- Topography
- Electrical well surveying

POSSIBLE CRITERION FOR DISTINGUISHING MARINE AND NON-MARINE SEDIMENTS[1]

A. J. CROWLEY[2]
Wichita, Kansas

The writer recently made a somewhat detailed study of the potash feldspars of a number of known marine, and known non-marine sediments. The results obtained were so strikingly uniform that they are deemed worthy of mention for the purpose of further investigation, and are presented herewith with this purpose in mind.

[1] Manuscript received, October 9, 1939.

[2] University of Wichita.

This study dealt with the secondary-growth potash feldspar, (1) as a cement in aggregates of feldspar and quartz grains, (2) as euhedral crystals, and (3) as secondary growth upon clastic feldspar grains.

This type of feldspar was found only in marine sediments, and in order of abundance occurred in shales, sandstones, and limestones. Considering that the secondary feldspar may have grown in the normal marine bottom environment, this distribution would be expected, especially with regard to limestone as it is probably cemented soon after its precipitation.

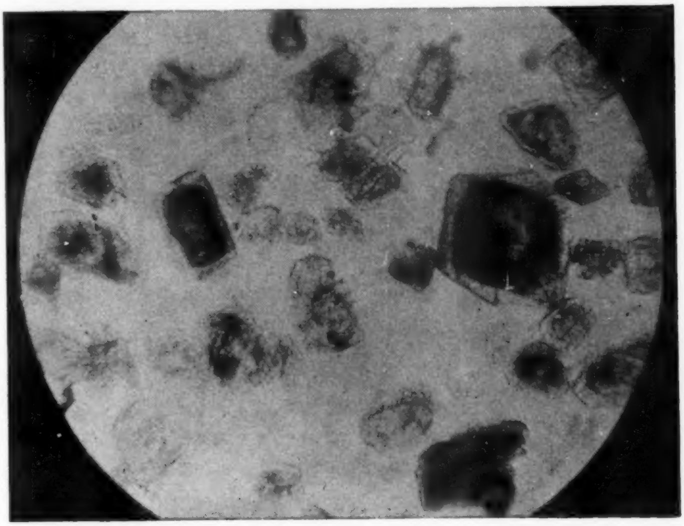

FIG. 1.—Feldspar taken from marine sandstone. ×60. Ordinary light. Attention is called to well developed secondary growth, and fresh euhedral grains.

No secondary-growth feldspar of the type mentioned was found in any of the non-marine sediments examined. To be sure, some grains containing secondary growth were commonly encountered. However, they were, without exception, broken, or abraded, indicating transportation of the secondary-growth feldspar previous to its deposition in the non-marine sediment, and suggesting thereby its origin in an older rock, with subsequent transportation, followed by deposition in the younger non-marine sediment in which it was observed.

The procedure in obtaining the feldspar mentioned, was as follows. The sediment was broken up, treated with acids, to remove

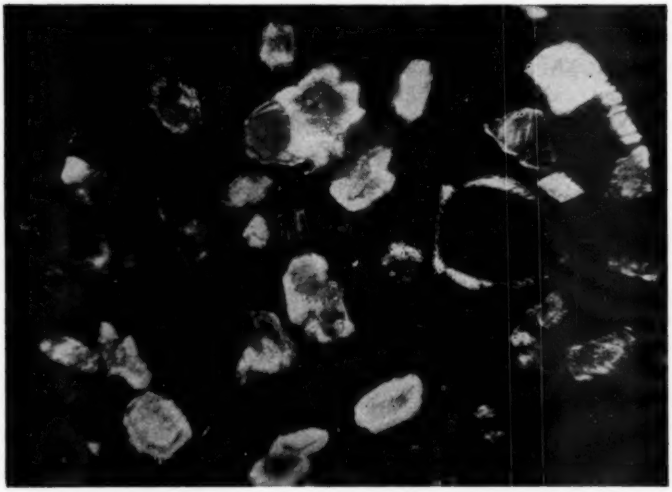

FIG. 2.—Feldspar from marine sandstone. ×60. Crossed nicols. Figures 1 and 2 are representative of feldspars in marine sediments.

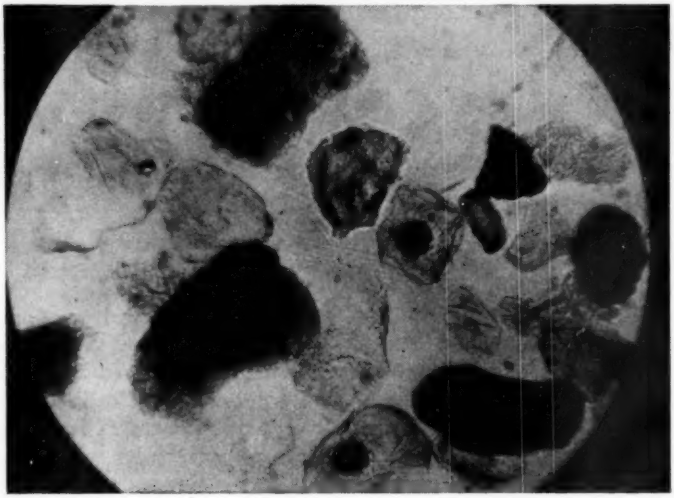

FIG. 3.—Feldspar from non-marine sandstone. ×60. Attention is called to high degree of kaolinization, broken secondary growth, and lack of fresh euhedral grains.

oxides, sulphides and carbonates, and then screened to remove particles smaller than 100-mesh. The feldspar was then separated by centrifuging in a bromoform-alcohol mixture of the correct density to permit the quartz and heavier minerals to settle to the bottom of the test tubes, and the potash feldspar and lighter minerals to float on the top of the solution.

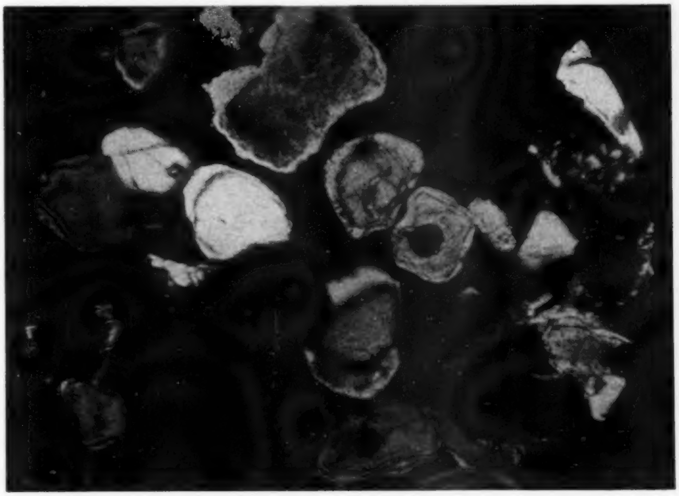

FIG. 4.—Feldspar from non-marine sandstone. ×60. Crossed nicols. Attention is called to broken secondary growth, and lack of fresh growth or fresh feldspar. Figures 3 and 4 are representative of feldspar in non-marine sediments.

More than a hundred separations each, of marine and non-marine sediments, were made. For the sake of brevity, a few of each are tabulated.

NON-MARINE

1. Red clastic series (Minn.). Feldspar rounded and abraded, no euhedral crystals, little or no secondary growth
2. Chugwater formation (Wyo.). Same
3. Spearfish formation (S.D.). Same
4. Opeche formation (S.D.). Same
5. White River series (S.D.). Same, plus some felspathic glass evidently volcanic ash
6. Florissant beds (Colo.). Same
7. Triassic fanglomerate (Suffern, N.Y.). Same. No ash or glass
8. Triassic redbed (Passaic, N.J.). Same
9. Triassic redbed (Booneton, N.J.). Same
10. Triassic sandstone (North Holyoke, Mass.). Same
11. Morrison beds (S.D.). Same

MARINE

1. Jordan sandstone (Minn.). Good secondary growth; feldspar fresh with some euhedral crystals
2. St. Peter sandstone (Minn.). Same
3. Decorah shale (Minn.). Same. Many crystals
4. Glennwood shale (Minn.). Same
5. Platteville limestone (Minn.). Same. Few crystals
6. New Richmond sandstone (Wis.). Same. Good crystals
7. Minnelusa sandstone (S.D.). Same
8. Pahasapa limestone (S.D.). Same
9. Whitewood formation (S.D.). Same
10. Englewood limestone (Ind.). Same
11. Niobrara "chalk" (S.D.). Same

In each case, and in the writer's experience, without exception, the marine sediments exhibited either, (1) well formed euhedral crystals of feldspar, (2) new growth about a nucleus of clastic feldspar, or (3) aggregates of feldspar and/or quartz grains cemented by secondary-growth feldspar.

In no case was this relationship observed in the non-marine sediments.

The accompanying microphotographs (Figs. 1–4) illustrate the points mentioned.

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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and available to members and associates.

LE GÉOLOGIE DES ALPES MÉRIDIONALES D'APRÈS LES LEVÉS RÉCENTS, BY L. U. DE SITTER

REVIEW BY R. D. REED[1]
Los Angeles, California

"Le géologie des Alpes méridionales d'après les levés récents" (Geology of the Southern Alps according to Recent Surveys), by L. U. de Sitter. *Geologie en Mijnbouw*, N. S., Vol. 1 (Leiden, April, 1939), pp. 68-91.

The plain of the Po, which is 50-60 miles wide in its upper part and about 225 miles long from Turin to the Adriatic, lies between the Apennines on the south and the southern Alps on the north. Several large rivers come down out of the Alps and cross the provinces of Piedmont, Lombardy, and Venice. Followed upstream to the edge of the mountains, some of these rivers lead to such beautiful lakes as Maggiore, Como, and Garda. The part of the southern Alps in which the lakes lie is composed largely of Mesozoic limestone, with peaks rising to elevations of 2,000-2,500 metres. North of this marginal belt, which is sometimes called the Southern Calcareous Alps, lies the Catena Orobica (part of the Insubrian zone of Jenny) composed of crystalline schists.

Strange as it may seem, the geologists of the University of Leyden have been busily mapping this strip of the southern Alps for 15 years or more, and have published many papers about its details. Professor de Sitter now undertakes to make a few generalizations and particularly to trace the historical evolution of the Bergamasque Alps, which adjoin the Lombard Plain and stretch eastward from Lecco and Como lakes for 40 miles or more.

If one may judge from the amount of detail shown in de Sitter's charts and sections, the outcrops in this area must be very good. The geology, though complicated enough, seems to be simpler than many earlier writers had anticipated. Thus the northern belt, or Catena Orobica, turns out to lack the properties it should have if it were a vertical "zone of roots."

Besides the textual discussion, de Sitter gives a detailed stratigraphic chart, a series of columnar sections, several well drawn structure sections, and a black-and-white geologic map. He explains many interesting matters, such as the relation of thrusts to lithology and to thickness changes, and the features that seem to determine whether the thrusts came from north to south or from south to north.

Geologists who are led, perchance by stories of the marvelously clear water of Lake Como or by a desire to see Virgil's old home or by advertising, to visit Lake Como and the Bergamasque Alps, should by all means put de Sitter's paper in their pocket and stay over a few days to see some good geology and to master one of the more readable short accounts of an important region in the Alps.

[1] Chief geologist, The Texas Company (California). Manuscript received, August 28, 1939.

ATLANTISHEFT, GEOLOGISCHE RUNDSCHAU

REVIEW BY R. D. REED[1]
Los Angeles, California

Atlantisheft (Atlantis Number) *Geologische Rundschau*, Bd. 30, Heft 1–4 (1939). 400 pp., many figures, 6 plates, Ferdinand Enke Verlag, Stuttgart.

In January of this year the Geologische Vereinigung held a symposium on Continental Drift. As several of the members noted, their symposium came about 10 years after the appearance of the Association publication, *Theory of Continental Drift* (1928), which embodied the results of our symposium of 1926. Partly because of this historical fact, but mainly because of the great interest of some of the contributions to the later symposium, I propose to review at some length the collection of papers that have resulted from it. After some introductory consideration of the drift problem, I shall give a list of the published papers and discussions, with brief remarks about some of them.

In order to limit their subject matter to those regions where data are most plentiful, the German geologists gave much attention to the origin of the Atlantic Ocean, a problem of prime importance in connection with the drift problem. Because of this geographical limitation, perhaps, a good many of the papers are geologically interesting to American geologists, whether or not they contribute much to a solution of the drift problem. In addition to the geological papers, moreover, there are many others on many subjects, such as biogeography, geophysics, astronomy, vulcanology, geography, and oceanography.

The first impression a reader of this collection receives is that opinion on the drift theory is still sharply divergent and that the holder of any view of the subject almost invariably seems certain of its correctness. Next, perhaps, the reader notes a striking tendency for geologists to reject the hypothesis for geophysical reasons, while many geophysicists accept it—apparently—for geological reasons. Again, he seems to sense a certain vagueness about many of the arguments for and against the hypothesis. Thus as a favorable argument, South African rocks and fossils are repeatedly stated to be "similar" to those of Argentina. But how similar? And how similar should they be to prove that drift did or did not occur.

Dr. Alfred Senn[2] once studied the succession of Tertiary orbitoids in Venezuela and in Morocco. The two sections were amazingly similar in very many respects: a good argument for drift since the Miocene, perhaps. He next assembled similar data for the Dutch East Indies, however, and found the resemblance almost equally striking, with no possibility that drift had anything to do with it. Similar provinces simply have a similar succession of beds and fossils in these cases: and if in these cases, why not in many others?

This aspect of the problem is treated by several authors of the symposium. Thus, Hans Cloos suggests the desirability of reducing the similarities to graphs. In this way, perhaps, we might find out if there is a sudden change at the Atlantic shore line in the rate of lateral variation in properties of continental rocks and fossils. Without using the graph form, Kummerow argues

[1] Chief geologist, The Texas Company (California). Manuscript received, August 28, 1939.

[2] A. Senn, "Die stratigraphische Verbreitung der tertiären Orbitoiden," *Eclogae geol. Helvetiae*, Vol. 28, No. 1 (1935).

from the Paleozoic ostracod faunas of Europe and America that a broad Atlantic Ocean existed in their lifetime. His data are too incompletely given to permit their importance to be judged but they are promising.

Rutsch disagrees with Kummerow and argues from some Early Tertiary mollusks that tropical America must have been close to north Africa when his fossils were alive. Again, however, he has simply found a greater degree of resemblance than he thinks there should be, without proving anything about how much resemblance is possible if the present distance between the localities existed then. Kummerow has tried to establish a *rate of change* and to show that the ocean interrupts the "curve"; while Rutsch, it seems to me, is assuming a rate of change.

I consider this matter of very great importance, since it ties in with several important tectonic problems. Suppose one of the "pulsation" theories should turn out to be true: if it should, practically all of these simpler arguments from similarity would be left baseless. To my eye, as a matter of fact, their base looks shaky anyhow.

Another impression one receives from reading these papers relates to the degree to which the drift theory owes its popularity, if not its inception, to the rise of the nappe theory. Following such nineteenth century pioneers as Bertrand and Schardt, in the early years of the twentieth century Termier, Lugeon, Haug, and others popularized the idea that the Alpine nappes had resulted from lateral movements of scores, perhaps hundreds of miles. The extent of these movements is of course not even yet a matter of agreement, as is shown by K. Leuchs' interesting article in the collection under review. Whatever their extent may prove to be, however, there seems to be a great likelihood that their recognition had much to do with paving the way for the drift hypothesis. When a drift addict is crowded he often seems to take comfort from the fact that modern students of folded mountains nearly all admit crustal shifting of at least some miles in extent; as an argument in favor of the possibility of drift, furthermore, it seems to me that he is entitled to his feeling of comfort.

But did South America actually as a matter of historic fact split off from Africa, drift slowly westward on its sial base, and thus create the big crevasse called the Atlantic Ocean? That drift is possible does not prove that any such event as this occurred. The answer to whether it did, it seems to me, might come if we could ever work out anything substantial about the geologic history of that ocean by means analogous to those we use in working out the history of a continent. Increased knowledge of the geologic history of Africa and South America will undoubtedly be helpful, but possibly not in itself sufficient. Supplementary material about the ocean bottom is still scarce.

An approach to a solution by the means just suggested is undertaken in the present collection by Hans Stille. Upon first glancing through his paper one may suspect that Stille is trying to discredit continental drift by showing that criteria much like those used to support it are available for use against it. After re-reading the paper carefully, however, I see no reason to doubt that the author intended merely to make a careful analysis of the meager data now available for an account of the geologic history of the Atlantic Ocean. The result, it seems to me, is a masterly piece of deductive reasoning.

As important contributions to American geology I wish to mention in particular three papers in addition to Stille's. First, H. Gerth has a very inter-

esting comparison of South American and African geology, which is summarized in this review. Second, H. Keidel has a very long paper on the supposed Gondwana arc of Argentina. Third, W. Staub contributes two interesting maps and a brief text on Eastern Mexico considered as the northwest end of the Mediterranean orogenic zone. His tectonic map extends north to include Texas and other states as far as southeastern Idaho.

Following is a list of the papers, with longer or shorter comments on many of them. Those listed without comment are brief remarks or discussions.

1. "Geophysical Basis of the Drift Theory" (pp. 3–5), by Kurt Wegener.

The brother of Alfred Wegener briefly comments on the geophysical data, particularly new data, that seem to confirm the drift theory.

2. "The Source of the Earth's Energy" (pp. 6–7), by Bailey Willis.

A brief letter regretting that the author is unable to take part in the symposium.

3. "The Problem of Continental Drift" (pp. 8–9), by W. A. J. M. van Waterschoot van der Gracht.

The leader of the Association's symposium in 1926 regrets his inability to participate in the later one and comments briefly on the present status of the drift hypothesis.

4. "The Permanence Problem on the Basis of the Undation Theory" (pp. 10–20), by R. W. Van Bemmelen.

The author shows that if the Undation Theory is true, continental masses may sink into oceanic depths. Thus, greater vertical movements than most geologists contemplate become probable, extensive lateral movements improbable.

5. "Tectonics of the Atlantic Ocean" (pp. 21–27), by Friedrich Nölke.

A philosophical discussion of some of Wegener's assumptions, which the author finds inadmissible. Vertical movements of the crust are large and important, lateral movements comparatively slight and unimportant.

6. "The Tectonics of the Atlantic Ocean" (pp. 28–51), by Richard A. Sonder.

Assumes the contraction theory, denies continental drift, also the possibility that continental masses of any size ever existed on the site of the present oceans. Even land bridges are admitted only with hesitation. A good deal about the evolution of granitic rock from basaltic (continental from oceanic).

7. "Source of Volcanic Energy and Origin of Sial" (pp. 52–60), by A. Rittmann.

Rittmann suggests that the primeval magma of the outer part of the young, molten earth was alkali basalt; that the gas content of this magma was in equilibrium with an atmosphere at least 270 times as dense as the present one; that volcanic energy is due to the differential pressure between gases in the present magma (which have inherited much of their ancient pressure) and the tenuous atmosphere of the present day; that Sial was produced by the granitization of the first sediments of the primeval oceans, which then rose isostatically to become continents of modern type. A stimulating theoretical discussion.

8. "Upper Cretaceous Alkali Magmas along the Atlantic Margin of Africa (pp. 61–63), by E. Krenkel.

This brief article contains notes on a belt of occurrences of alkali basalt stretching from Cape Colony northward to the Cameroons and on through the basin of Lake Chad, the Sahara, and Libya, to the Mediterranean Sea. Volcanic activity from the Cameroons southward culminated in the Senonian. Northward from the Cameroons it was dominantly Late Tertiary.

9. "Stratigraphic and Faunal Foundation for the Geologic History of the South Atlantic Realm" (pp. 64–79), by H. Gerth.

Omitting a discussion of pre-Cambrian conditions, Gerth notes that the presence of Cambrian rocks in western South America and eastern Australia, and their absence in eastern South America, South Africa, and western Australia, suggests the existence of a Gondwana continent at the beginning of the Paleozoic. In Upper Silurian time the sea transgressed in northern South America (Amazon Basin) and in the Sahara region. In Devonian time there was an extensive transgression, the deposits of which are found in South Africa, the Falkland Islands, and in southern South America as far as Bolivia and southern Brazil. So similar are all these rocks petrologically and faunally that Gerth thinks the shoreline connecting them must have had a direct course; and further, that if the distance between continents was shorter then than now the similarities would be more readily understandable.

In northern South America we find Devonian deposits in the Amazon Basin and locally in Colombia and Venezuela. The fauna is unlike that of the southern Devonian but similar to that of some North American formations. A Devonian occurrence in the Gold Coast yields fossils that Gerth considers similar to those of the Amazon Devonian.

Carboniferous rocks are not certainly known on the Atlantic coast of either continent.

Gerth considers the Permo-Triassic beds very important for an understanding of the common history of the two continents. His correlations are different from du Toit's or Krenkel's. The Brazilian *Mesosaurus* beds he considers Upper Permian, the African Lower Permian. The highly fossiliferous Lower and Middle Triassic beds of Africa are missing from South America. Instead of using this fact as an evidence of striking differences between the continents, however, Gerth uses it to blunt the edge of another difference, that is, the absence of the Karroo fauna from South America. How can the fauna be present, he asks in substance, when the beds are represented only by a disconformity? Brazilian Upper Triassic beds, known to be Karnic from a small marine fauna, carry a saurian fauna, but it is related not to Karroo reptiles but to a wide-ranging group represented also in East Africa east of Lake Nyassa.

Triassic marine beds seem to be unrepresented in South Africa. In the Permian, however, the sea occasionally invaded lowland areas in both continents and was presumably not far away at any time. In both regions marine beds occur above fluvio-glacial sediments, also referred to the Permian by Gerth.

No marine Jurassic deposits are known from the Atlantic coast of either continent; an indication, the author thinks, that the South Atlantic ocean was not yet in existence. Marine Triassic beds occur in southern Brazil, as noted above, but he thinks the transgression came in from the Pacific.

Similar Lower Neocomian Trigonias and Ammonites in Argentina and South Africa suggest a direct shallow-water connection, and thus continued absence of the South Atlantic. Aside from a single occurrence of Barremian ammonites in Angola, the oldest marine Mesozoic deposits on either coast are Albian, and these occur in considerable thickness on both. Since the Upper Cretaceous sea swept down from the Mediterranean area entirely across the Sahara, however, the facts do not definitely prove that North and South Atlantic were even yet directly connected between Brazil and Senegal.

During the Tertiary the sea margin seems to have occupied about its present position with respect to the African and South American margins. Only in Argentina did a Tertiary sea invade a continental area much past the present shoreline.

In his concluding pages Gerth discusses the remarkable absence, or at best extreme poverty, of the reef-coral faunas in the South Atlantic. Their relations, he believes, are with the much richer Caribbean faunas from which they are probably migrants.

Since many of the facts cited in the foregoing discussion of Gerth's paper are given also in several others in the symposium (Knetsch, Hennig, Keidel, *et al.*), I have chosen to give them once for all, and to treat the other papers more briefly. The interpretation of some of the facts is not a matter of agreement among all the writers concerned.

10. "Episodes in the History of the South Atlantic Region" (pp. 80–85), by E. Hennig.

The author of "Afrika" in the series *Regionale Geologie der Erde* discusses the origin of the drift hypothesis and several facts bearing upon its validity. He rejects the hypothesis and holds that even Suess' concept of a Gondwanaland does not fit the facts of today very well. He inclines to the theory of land bridges as a possibly acceptable compromise.

11. "Fossil Land Faunas and the Atlantic Problem" (pp. 86–88), by F. von Huene.

A direct land connection between Africa and South America is suggested for the older Permian, an indirect one—perhaps across Antarctica—for the early Upper Triassic. Between Europe and North America, a direct one is indicated for Middle Permian. Uppermost Jurassic faunas of North America and East Africa are remarkably similar. Upper Cretaceous faunas of North and South America are also similar.

12. "The Atlantis Problem in the Light of New Data of Quaternary Geology" (pp. 89–94), by H. de Terra.

De Terra discusses the legendary Atlantis, and summarizes archeological and geological data bearing upon it. He points out that the American Paleolithic culture ("Folsom") is related to cultures of northeast Asia, not to those of western Europe. Hence, there is no suggestion that the first Americans walked westward across Atlantis from Europe. He concludes with some interesting data about the extent of late Cenozoic vertical movements in the Himalayas, East Indies, and elsewhere.

13. "Paleontology and the Drift Hypothesis" (pp. 95–99), by E. H. Egmont Kummerow.

A brief paper given over largely to arguments against one or another aspect of the drift hypothesis. The most striking argument is given briefly. It is that east American and west European ostracod faunas of the Middle Paleozoic should show reasonably close correspondence if Wegener's ideas are true. The author cites the results of his own studies in Central and Western Europe to show something of the rate of change of faunas with distance. Thus of 76 German and Belgian species, 28 occur across the Channel in Great Britain and Ireland. In America, on the contrary, scarcely a single European species occurs; instead there are many strange genera, subfamilies, and even families. Since the facies of the ostracod-bearing deposits is the same in both continents, the facts suggest strongly that during the Paleozoic Europe and North America were separated by a wide ocean.

The author's discussion of ostracod habits and the conditions of occurrence of their fossils adds weight to his conclusion, which is here stated pretty baldly. If his data are as good as his own statement suggests, it would seem that he has the material for constructing an illuminating curve of the type suggested by Cloos on a later page of the symposium (p. 361).

14. "Biogeographic Research and the Atlantis Question" (pp. 100–111), by Otto Wittmann.

A fairly technical discussion of the contributions that zoögeographic research may make to paleogeography. The author holds that drift is not to be proved by zoögeographic considerations, but that it is a good working hypothesis for numerous zoögeographic problems.

15. "Geographic Objections to Wegener's Theory of Continental Drift" (pp. 112–20), by Walter Behrmann.

The author believes that Scandinavia enjoyed an oceanic climate during the Tertiary, as it could not have done if Greenland had lain close to or against its west coast. Since the Pliocene he believes that many critical regions such as Angola, German East Africa, North Australia, and Central Brazil have not been affected by a shifting of their latitude and longitude. A map of the world (Fig. 1) shows by a series of widely distributed circles the numerous areas that can not have shifted since Pliocene and Quaternary. Neither continents nor poles have shifted essentially, at least since the Pliocene, Behrmann concludes.

16. "The Surveying of Morphologic Features of the Sea Bottom by Means of Echo-Sounding" (pp. 121–31), by A. Defant.

An oceanographer discusses the limits of error in echo-sounding and in the drawing of submarine contours. He reproduces, among other examples, the U. S. Coast and Geodetic Survey's map of the vicinity of Bogoslof Island but doubts if the minor features shown can all have been demonstrated by the soundings that were available.

17. "Major Bottom Features of the Deep Atlantic Basin" (pp. 132–37), by Georg Wüst.

Another oceanographic contribution, illustrated by a map showing—and naming—the ridges and basins found on the bottom of the Atlantic Ocean.

18. "The Origin of the Atlantic-Arctic-Ocean" (pp. 138–47), by Alex. L. du Toit.

Du Toit here summarizes the arguments favoring drift. Nearly all of them are given at greater length in his 1937 book, *Our Wandering Continents*. It is remarkable how many different evidences and arguments seem to strike this author as practically conclusive in favor of the drift hypothesis.

19. "The 'Gondwanids' of Argentina" (pp. 148–249), by H. Keidel.

A long account, giving many details of the geology of the Pre-Cordillera, the Sierras of Buenos Aires, and intervening districts. The author finds that the simple concept of a Gondwanid arc across Argentina and Cape Colony, and of a "Samfrau" geosyncline, becomes less definite and convincing the more details one learns about the area involved. His discussion is much more conservative than several that have appeared on the same subject but should not for that reason be neglected. The concept of a Gondwanid arc in Argentina is a fascinating one, even if we neglect its implications for the drift theory; but at this stage of the investigation there is no harm in giving a little attention to the uncertainties.

20. "Atlantis (Geology of the South Atlantic Ocean)" (pp. 250–83), by Georg Knetsch.

Prepared to be read as one of the introductory papers at the symposium, Knetsch's contribution is an excellent summary of the geologic aspects of the problem. It is par-

ticularly interesting because in it the author cites the views of many other contributors to the symposium.

On the subject of continental drift, Knetsch considers the theory unproved but not utterly impossible. He believes also in the probability of greater up-and-down movements of the crust than do many geophysicists. His paper ends with suggestions for a program of research that might solve these problems. It is followed by a long list of publications used.

21. "Remarks on the Atlantis Convention in January, 1939" (p. 284), by A. Rittmann.

A brief note in which the author illustrates one great difficulty in analyzing the evidence for and against continental drift. The difficulty: Too much specialization is needed in too many directions. Illustration: the theory that the Middle Atlantic Ridge is a young fold neglects the fact that it has "Atlantic" rather than "Pacific" volcanic rocks.

22. "Tentative Analysis of the Greater Movements of the Earth's Crust" (pp. 285–96), by W. H. Bucher.

A slightly modified German version of the author's Anniversary Day address at the Geological Society of America's New York meeting, December, 1938. Published in English in the *Bulletin* of the Society, 1939. A stimulating discussion in either language. Bucher argues for large up-and-down crustal movements, with some lateral shifting connected with orogenic processes.

23. "Remarks on the Atlantis Convention" (pp. 297–302), by W. A. J. M. van Waterschoot van der Gracht.

Dr. Van der Gracht feels that, though the drift concept is still a very probable one, the details of the sial shiftings and the questions of causes have not become clearer with the lapse of years.

24. "The Problem of Transoceanic Continental Connections" (p. 303), by S. von Bubnoff.

A note on the different times of folding and flooding of northern and southern continents and the conclusion that may be drawn as to continental connections; also a brief discussion of the difficulty of interpreting sea-bottom morphology.

25. "Movement of the Continents According to the Wegener Theory" (pp. 304–08), by Ludwig Becker.

An astronomer undertakes to determine whether or not at any given time the forces tending to cause polar shifting and continental drift were acting in the right direction to do what Wegener thought they did. The competency of the forces is not discussed.

26. "Discussion of Paper by Kirsch" (p. 309), by H. Reich.

27. "Discussion" (p. 310), by G. Kirsch.

28. "Work of the German Iceland Expedition, 1938" (pp. 312–14), by Oscar Niemczyk.

Iceland has a rigid, fractured crust overlying subterranean magma currents. The expedition mentioned did preliminary surveying, mapping and gravity work. Succeeding expeditions are to follow at intervals to repeat some of the measurements and to find out just what surface and subsurface changes are taking place in Iceland and whether they resemble in any respects those of less evidently volcanic areas.

29. "Cordilleran-Atlantic Interrelations" (pp. 315–42), by Hans Stille.

This fascinating paper is mentioned on an earlier page of this review. Its data are assembled in several striking figures. Everyone interested in drift or in the origin of the Atlantic Ocean should study it carefully.

30. "Trans-Atlantic Fold Connections" (pp. 343–45), by H. Stille.

Discussion of possible cross-folds on the bottom of the Atlantic; closes with some good arguments as to the nature of the Sierras of Buenos Aires and their relations to the Cape Mountains and Falkland Islands.

31. "Eastern Mexico, the Northwest End of the Mediterranean Orogenic Zone" (pp. 346–51), by Walther Staub.

A brief paper, which however takes account of the views of Boese, Burckhardt, Muir, Kellum, Imlay, and other geologists who have discussed the tectonics of northeastern Mexico. The geologic map is black and white and covers the region east of the Sierra Madre Oriental from an east-west line just north of the San Carlos Mountains to one about 50 miles south of Tuxpan. In other words, it covers the oil region of northeast Mexico, and is compiled from maps by the author, Muir, Heim, Jenny, and others. The scale is 32 kilometers to the inch. The tectonic map is on a scale about a tenth as large.

It covers nearly all Mexico and Texas, and extends north to southern Montana and southeastern Idaho.

32. " 'Pingen' Investigation and the Wegener Theory" (p. 352), by K. Lehmann.

33. "Tectonics and Lithogenesis" (pp. 353–56), by Kurt Leuchs.

The author believes that sedimentary petrology may contribute a great deal to the problem of continental drift. He points out that it has already made the extreme form of the nappe theory impossible in the Alps, and has also been fatal to certain concepts as to the size and shape of the Vindelician land. The discussion bears more on the nappists than on Wegener.

Professor Leuchs is the author of "Geologie von Asien" in the *Geologie der Erde* series; also of "Zentralasien," in the *Handbuch der regionalen Geologie.*

34. "Iceland and the Problem of Continental Shifting" (pp. 357–58), by F. Bernauer.

A brief summary of some volcanic phenomena in Iceland that are suggestive in connection with the origin of the Middle Atlantic Ridge.

35. "On the Paper by W. Bierther, 'Investigations in Northeast Greenland' " (p. 357), by H. G. Backlund.

36. "Discussion of the General Account of Continental Movement, by G. Knetsch" (p. 359), by H. G. Backlund.

37. "Terrestrial Reptiles of the Karroo and Gondwana Fauna" (p. 359), by F. von Huene.

Faunal considerations lead von Huene to doubt that a "South Atlantic Gondwanaland" existed in early upper Triassic, the only part of the Triassic for which comparisons can be made between African and South American faunas. A less direct connection, perhaps across Antarctica, would serve better. In any case, the continents were undoubtedly separate, he thinks, in the Cretaceous.

38. "A Criterion for Corroborating or Refuting the Wegener Drift Theory" (p. 360), by F. von Huene.

A proposal for world-wide paleoclimatic studies as a means of proving or disproving Wegener's views.

39. "Method in Trans-Atlantic Comparisons" (p. 361), by Hans Cloos.

Suggests a graphic method for displaying such data as those already mentioned as being found in Kummerow's paper. A stimulating suggestion.

40. "Tropical American Tertiary Faunas and Continental Drift" (pp. 362–72), by R. Rutsch.

Aroused by Kummerow's views, Rutsch discusses the relation of faunal similarities to the drift problem and cites evidence to show that faunal relations between tropical America and North Africa were so close in the Paleocene and probably also in the Eocene as to exclude the idea that the Atlantic Ocean existed then in its present form. Continental drift is suggested but not proved, the author concludes.

41. "Progress in Making a Submarine Map, Scale 1:5,000,000" (pp. 373–81), by Theodor Stocks.

An oceanographic contribution, needed as background for studies of the Atlantic or other ocean bottom. It does not deal directly with continental drift.

42. "Paleogeography and Atlantic Deep Sea Sediments" (p. 382), by W. Schott.

43. "Oral Discussion of the Oceanographic Papers (p. 383), by O. Pratje.

44. "Remarks on the Atlantic Problem, Made after the Three Oceanographic Papers Were Read" (pp. 384–86), by Carl Troll.

In conclusion, what are we to believe about continental drift, and what about the origin of the Atlantic Ocean? Did the ocean originate as a water-filled crevasse in the midst of a disintegrating continent? Or did large parts of it come into existence by the downwarping of areas that had previously stood above sea-level? Or, finally, has the ocean always existed, as many advocates of the permanence doctrine have long held?

The evidence in favor of extensive downwarping seems good and seems to be increasing in amount. Submarine valleys constitute good evidence to many minds; thick marine sections on old land areas (Gulf Coast Tertiary on Llanoria) are possibly better. As a perusal of the *Atlantisheft* shows, however, many geologists still reject downwarping as inconsistent with isostasy. Others argue, plausibly I think, in favor of changes in sial thickness or other subcrustal

events as means by which the inconsistency may be removed. If we accept downwarping as a major factor in ocean-making, however, we must still admit the possibility that some continental drift may have occurred. If the Andes demonstrate post-Coniacian crustal shortening, then South America has moved west or the Pacific Ocean basement has moved east, or both have moved. By similar reasoning, Africa and India must be suspected of having moved northward and Australia of having moved eastward or northeastward. All of these movements would be in the right direction to assist in creating the South Atlantic and Indian oceans. Thus, as Bucher points out, drift seems to be a necessary consequence of the folding that has certainly occurred; but not necessarily as prominent a consequence as some friends of the hypothesis maintain.

Finally, there are some good theoretical reasons for believing that large ocean basins must have existed at any rate since before the Paleozoic era; and there are none for refusing to believe that the sites of these basins may largely have coincided with some of the present oceans. Hence, though somewhat shaken, the devotees of permanency may still hold on, possibly forever.

ANNUAL REVIEWS OF PETROLEUM TECHNOLOGY, VOL. 4, BY THE INSTITUTE OF PETROLEUM

REVIEW BY STANLEY C. HEROLD[1]
Los Angeles, California

Annual Reviews of Petroleum Technology, Vol. 4 (Covering 1938). Published by The Institute of Petroleum (formerly The Institution of Petroleum Technologists), The Adelphi, London, W. C. 2. (1939). Cloth. 478 pp., 6×9 inches. Price, 11 s. 0 d.

The present volume is the fourth of a series of annual reviews which have appeared in book form. Earlier issues, beginning in 1924 with a review covering 1923, appeared on the pages of the Institute's *Journal*. Each issue is in fact a symposium reviewing the literature and noting the progress in various departments of petroleum technology pertaining to the preceding year. The present issue, edited by F. H. Garner, includes 28 such departments, each one of which is treated by an author or by authors well versed in the particular subject.

The table of contents is beautifully arranged. Department headings appear in large type, followed by the author's name with or without sholarship degrees and memberships in italics. Indented under the headings are synopses that designate subheadings appearing within the text. These reveal the items concerning which progress, according to published articles in 1938, appears to have been made. As an illustration the first department is fully described as follows.

PETROLEUM GEOLOGY. *By A. I. Levorsen*

General Features—Origin of Oil—Time of Oil Accumulation—Sedimentation—Shoestring Sands—Salt Domes—Ground-Gas Surveys—Aerial Mapping.

The text is divided in accordance with the subheadings, and the department closes with a list of "References," this being a bibliography of the literature cited in the text.

[1] 811 West 7th Street. Manuscript received, September 21, 1939.

Stripped of degrees, memberships, and synopses the Contents continue as follows.

The book closes with two indexes: one for names of cited authors and the other for detailed subjects. The former refers only to names as they appear in the "References" which terminate the departments.

It is observed that the literature reviewed by the writers comprehensively covers the petroleum industry inasmuch as it includes exploration, exploitation, transportation, refining, products and by-products, internal combustion engines, chemical and physical analysis, and statistics. Most of the writers are British, some are American. The first two papers are by prominent members of the Association. The cited literature is about evenly divided between American and foreign publications, and of the latter of course the British predominate.

There is no single publication of the same scope appearing in this country. We who are engaged in the exploration and exploitation of petroleum find it exceedingly difficult to keep abreast of advances in the allied branches of the industry because of the lack of conveniently available and concisely written material. This volume places salient facts easily within our reach. A delightful feature of the text is its free and easy style to be noted throughout the book. Quotation marks seldom appear; the stories run along smoothly and quite casually with superscript numbers which direct attention to the bibliographies. Conflicting views, where present, are set forth quite impartially. The book is

recommended to petroleum geologists for informative reading and convenient reference. Some who do not possess the earlier volumes may wish to have the complete set to date. Those who already have them will find this the best yet produced. If one is not too meticulous in matters of book collecting, a set through the years may well begin with the present issue.

RECENT PUBLICATIONS

CALIFORNIA

*"Structural Features of a Landslide near Gilroy, California," by K. B. Krauskopf, S. Feitler, and A. B. Griggs. *Jour. Geol.*, Vol. 47, No. 6 (Chicago, August–September, 1939), pp. 630–48; 11 figs.

*"West Montebello Oil Field," by Harold M. Preston and Vernon L. King. *Petrol. World*, Vol. 36, No. 9 (Los Angeles, September, 1939), pp. 19–23; 1 geol. section, 1 structure map, 1 production curve.

Oil and Gas Fields of California. Map compiled by G. B. Richardson, assisted by Jane Hanna. Scale, 1:500,000 (1 inch = nearly 8 miles). 64×44 inches. Sold by Director, U. S. Geological Survey, Washington, D. C. Price, $0.50.

"Geology and Oil Possibilities of Southwestern San Diego County," by Leo George Hertlein and U. S. Grant IV. *California Jour. Mines and Geol., State Mineralogist's Rept. 35* (San Francisco, 1939).

CHILE

*"Recent Sediment Formation in Concepcion Bay, Chile," by H. Falke. A study of the origin of bituminous sediments. *Petrol. Zeit.*, Vol. 35, No. 34 (Berlin, September 5, 1939), pp. 640–44; 6 illus.; No. 35 (September 15), pp. 658–65; 12 figs. In German.

EUROPE

*"Carboniferous and Permian in the Southern Alps and Southeastern Europe," by Franz Heritsch. *Geol. Rundschau*, Vol. 30, No. 5 (Ferdinand Enke Verlag, Stuttgart, August 15, 1939), pp. 530–88. In German.

FLORIDA

*"Scenery in Florida Interpreted by a Geologist," by C. Wythe Cooke. *Florida Geol. Survey Bull. 17* (1939). 118 pp., 58 figs.

*"Notes on the Upper Tertiary and Pleistocene Mollusks of Peninsular Florida," by W. C. Mansfield. *Ibid., Bull 18* (1939). 75 pp., 4 pls., 5 tables.

GENERAL

"Ground Water in the United States, a Summary of Ground-Water Conditions and Resources, Utilization of Water from Wells and Springs, Methods of Scientific Investigation, and Literature Relating to the Subject," by O. E. Meinzer. *U. S. Geol. Survey Water-Supply Paper 836-D* (1939). Pp. 157–232; Pl. 15, Figs. 11–41. Supt. Documents, Govt. Printing Office, Washington, D. C. Price $0.15.

"Bibliography of North American Geology, 1929 and 1930," by J. M. Nickles. *U. S. Geol. Survey Bull. 834* (1931, reprinted without revision, 1939). 280 pp. Price, $0.45.

**Technology, Employment, and Output per Man in Petroleum and Natural-Gas Production*, by O. E. Kiessling, J. Brian Eby, Lew Suverkrop, J. S. Ross, R. E. Heithecker, W. B. Berwald, Andrew W. Rowley, M. A. Schellhardt, Richard Sneddon, Boyd Guthrie, Herbert Schimmel, and J. C. Albright. *U. S. A. Work Projects Administration National Research Project and Department of the Interior Bureau of Mines Rept. E-10* (July, 1939). 349 pp., 30 figs. (text charts), 3 appendix charts, 3 text tables, 31 appendix tables, 33 illustrations (page-plates of photographs).

*"Atlantic Submarine Valleys of the United States and the Congo Submarine Valley," by A. C. Veatch and P. A. Smith. *Geol. Soc. America Spec. Paper 7* (New York, September 30, 1939). 101 pp., 5 charts, 10 pls., 28 figs. Text and illustrations in box, 7.75×9.75×2.75 inches.

*"*Supplement to a Selected List of Periodicals, Serials, and Books Dealing with Petroleum and Allied Subjects and Where This Material May Be Found in Some Oklahoma, Texas, and Louisiana Libraries, together with a Group of Subject Bibliographies on the Petroleum Industry Obtained from the Technical Department of the Tulsa Public Library*, compiled and collected by Clarence P. Dunbar and Lucille M. Dunbar. 224 mimeographed pages. 8.5×14 inches. Published by the Department of Conservation, Bureau of Research and Statistics, New Court Building, New Orleans, Louisiana (August, 1939).

Minerals Yearbook 1939. Review of 1938. "The complete Bureau of Mines official record of mineral production in the United States in 1938." Includes chapters on bituminous coal, coke, petroleum, natural gas, and natural gasoline. Supt. of Documents, Govt. Printing Office, Washington, D. C. Price: United States, Canada, and Mexico, $2.00; other countries. $2.50.

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 11 (NOVEMBER, 1939), PP. 1734-1746, 2 FIGS.

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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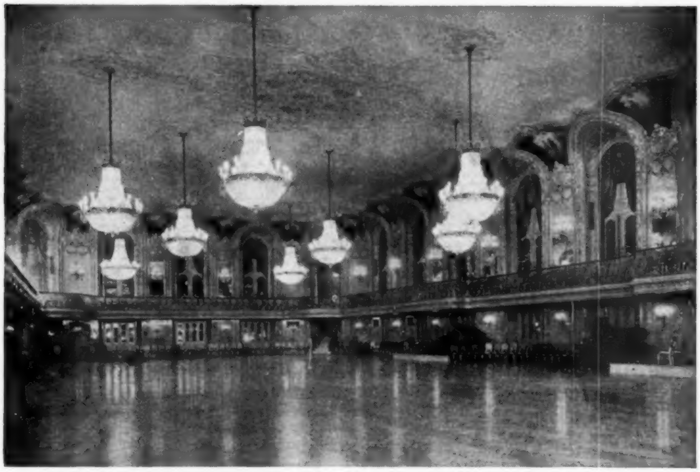
TWENTY-FIFTH ANNUAL MEETING, CHICAGO, APRIL 10–12, 1940

The twenty-fifth annual meeting of the Association will be held at the Stevens Hotel, Chicago, April 10, 11, and 12, 1940. Convention activities will really begin on Tuesday, April 9—the day preceding the opening of the technical program—when the business committee holds its annual meeting and the several other standing committees make their yearly reports. Also on the 9th, the exhibits of oil field and laboratory equipment will be ready for inspection by the "pre-convention" crowd. Already, more than half of the exhibit space has been taken,—an exceptionally early reservation that indicates a successful meeting at Chicago.



Grand Ballroom of Stevens Hotel, Chicago, where the twenty-fifth annual meeting of the Association will be held, April 10, 11, and 12, 1940.

The Society of Economic Paleontologists and Mineralogists will hold concurrent sessions as usual in the same headquarters hotel.

The Society of Exploration Geophysicists, as usual, will probably hold its meeting slightly in advance of the A.A.P.G. convention proper, so as to permit its members to attend both meetings.

This quarter-of-a-century convention is being held in Chicago at the invitation of the Illinois Geological Society whose officers are: president, Verner Jones, Magnolia Petroleum Company, Mattoon; vice-president, M. W. Fuller, Carter Oil Company, Mattoon; secretary-treasurer, Elmer W. Ellsworth, of W. C. McBride, Incorporated, Centralia, Illinois. At a meeting of the Society at Mattoon, October 26, attended by geologists from the Great Lakes District of the Association, Verner Jones was elected general chairman for all convention arrangements and appointment of the following chairmen was announced: technical program, A. H. Bell, Illinois Geological Survey; arrangements, J. V. Howell, consulting geologist, Tulsa, Oklahoma; field trip, M. M. Leighton, Illinois Geological Survey; finance, E. W. Ellsworth, W. C. McBride, Incorporated, Centralia.

MUTUAL RESPONSIBILITIES[1]

HENRY A. LEY[2]
San Antonio, Texas

The American Association of Petroleum Geologists has a Constitution, a Charter, and a Code of Ethics. These are our documents.

I commend our Constitution. In it is far more than the paper and ink on which it is printed. Through it runs, I think, the theme of wise and broad understandings of human nature and human institutions. Moreover, it contains no basic checks, blocks, and tackles to render administrations impotent. In it are no taints of commercial interests, no ulterior motives. To be true, it does not provide for all future eventualities, but amendments can be added as and when required.

Our Constitution makes no provision for our welfare, individually or as a group. Neither does it contain measures to be administered for the attainment of that end. Our Constitution and our Code of Ethics, wherever they refer to welfare, are concerned only with the public and with business enterprise outside the Association. We may not all agree, but I believe these are again wise approaches to difficult situations.

Constitutional Article II. *Object*, reads as follows.

> The object of this Association is to promote the science of geology, especially as it relates to petroleum and natural gas; to promote the technology of petroleum and natural gas and to encourage improvements in the methods of exploring for and exploiting these substances; to foster the spirit of scientific research amongst its members; to disseminate facts relating to the geology and technology of petroleum and natural gas; to maintain a high standard of professional conduct on the part of its members; and to protect the public from the work of inadequately trained and unscrupulous persons posing as petroleum geologists.

You will note that Article II takes cognizance of one situation, this in defense of the public-at-large:

> and to protect the public from the work of inadequately trained and unscrupulous persons posing as petroleum geologists.

I do not know precisely what this situation was 25 years past. To-day, we can state that it scarcely merits mention. But we do face situations far more insidious than those created by "unscrupulous persons posing as petroleum geologists." I refer now to current misuse of our maps and our reports, in whole and in part; to the easy free *entree* into geologic information and advice so prevalent to-day; and to the dissemination of false mouth-to-ear statements bearing on reputed scientific structural prospects. These situations more than any other single factor affect our welfare, individually and collectively, the consultant and the company man alike.

We do not possess the protective measures which surround the learned professions of law, medicine, and theology. Unlike those professions, we have absolutely no control of the usages, the interpretations, and the applicability of our work, once it passes out of our hands. How many of the untrained public-at-large would hazard attempts to diagnose problems in the fields of

[1] A talk before the South Texas Geological Society at its annual meeting in Brownsville, Texas, October 21, and before the Tulsa Geological Society at Tulsa, Oklahoma, October 25, 1939.

[2] President of the Association.

law, medicine, and theology? Yet we are faced with innumerable self-made analysts and diagnosticians all of whom regard themselves fully qualified to use our works. Often they indulge in the building of "Castles-in-Spain" which would put the Devil on the Mount of Temptation to shame.

Geology probably has one difficulty in common with the learned professions—too many men using these services can not bring themselves to understand why such services should be paid for.

Our modern problems concern not "the work of inadequately trained and unscrupulous persons posing as petroleum geologists," but the economic consequences of widely roaming self-made analysts and diagnosticians of geology; camp-followers of the industry seeking free geological tips and advice; and financially irresponsible men.

We have come far in the short time of a quarter of a century as an Association, and equally far as individuals in the three decades since applied geology first took root in the petroleum industry. That we are a profession or are not depends on our definition of profession. That we should or should not have measures of self-defense administered for the attainment of our welfare is open to discussion. Law and medicine were raised to high status only by gradual stages. You may be interested to know that in Colonial America (1641) the Massachusetts Body of Liberties allowed counsel "noe fee or reward for his paines." But, in the next 135 years, these men, lawyers, rose to such political and social power that they formulated and wrote our Federal Constitution. In another 135 years men permitted "noe fees" have become an integral part of business, finance, and industry, commanding the largest fees in our national economy.

We are applied petroleum geologists concerned primarily with prospecting. Structure and stratigraphy have always been foremost in our thoughts. We have taken far too little interest in business, economics, and the social structure in which we work. Perhaps if we concentrated less on the elusive structure contour and occupied ourselves more with the nature and attributes of business those situations which irritate some of us and affect the welfare of others, would find ready solution.

Among our problems is the subject of fees. Let me point out here that fees are criteria by which a man is judged both from within and from without this Association. I am fully aware that we do not live in an altruistic economy, and that families and individuals must live. Nevertheless, no man permanently benefits himself or his associates by resorting to cut-rate fees. A man's own opinions of his ability and his professional judgment are blazoned by the fees he exacts. And by those fees he is judged by his clients.

There is one more situation to which attention should be called. The quality of geologic work is not only dependent on personnel, but it is equally dependent on the tools made available to do the work. Geological departments denied use of critical working tools can not compete effectively. A combination of undermanned staffs and insufficient working tools never can produce satisfactory results. Staffs of this nature are always on the defensive. Their work is defensive. They can never take the offensive prerequisite to successful prospecting. This situation arises largely out of accounting procedure which holds that the first branch of the petroleum industry that can possibly show a profit is the production department when it has actually sold oil produced. Land and scouting arms in exploration are equally subject to this

disadvantage. Regardless of how successful we may be we are always a red expense on the balance sheet, never a black profit.

You may hold the viewpoint that these are matters calling, not for obscure statements, but an open direct advance on the problems and situations in the same sense and in the earnest manner that the lawyers and doctors do. That is a natural first reaction. As I have pointed out before, we are not faced with a host of "quacks," or with inadequately trained men practicing in high places. Ours, for the most part, are delicate problems and situations arising from our own acts and from within organizations that taken together comprise the oil industry. Legal ways and means of determining who shall and who shall not be entitled to practice geology by statutory provisions can never solve those problems facing us.

If we accept these premises, it is clearly evident that we best resort to unwritten measures. In the use and application of our science we coöperate among ourselves in a manner very surprising to men in other endeavors. We coöperate with mutual benefits to all concerned. We can coöperate, I believe, greatly to reduce disturbing situations and trying problems. Executive committees of this Association take cognizance of many situations. They act upon some, reflect on others, and elect to do nothing with the remainder.

It has been said that old men write in ink and young men in blood. This is as true in business as in war. The greatest heritage we older members can pass to our younger members is our business experiences.

COÖPERATION BETWEEN ARMS IN PROSPECTING[1]

HENRY A. LEY[2]
San Antonio, Texas

The courses of petroleum prospecting are most affected by management's concepts of prospecting techniques, and its understanding of the rôle and scope of each technique as it applies to special problems and different geographic or geologic territories. If management is not fully informed concerning these issues it can not prospect with fullest economic results. There is, therefore, a need of coöperation between management and the scientific arms in prospecting. But, this is not sufficient. Coöperation between arms in prospecting is equally necessary if our national economy is to obtain the maximum possible value from every dollar spent in prospecting. Notwithstanding all that may be written or spoken we have not fixed, within their practical limits, the range and amplitude of all arms in prospecting. Neither are we yet able to enter virgin territories forearmed with full knowledge of the precise technique best fitted to solve the prospecting problems of that territory. We do know that all arms in prospecting measure something, but what that something is we can not always be certain beyond defining it as an anomaly—hoping that it is a physical anomaly related to the earth itself, and not an instrumental error or a mental mirage.

[1] Presidential talk before the Dallas Geological Society at Dallas, Texas, October 23.

[2] President of the Association.

No arm in prospecting is an entity apart from organized prospecting—which exists as a branch of the petroleum industry engaged in the pursuit of petroleum discovery. All arms want to work; they want to work at their own technique; and naturally each seeks to extend its sphere of action.

To-day the road to petroleum prospecting is not a highway. Our approaches to prospecting are undergoing profound and perhaps disturbing transformations. Much is new and experimental; little is well established and accepted as universally applicable. The growth of the use and number of arms in petroleum prospecting and their complexities, within the short course of three decades, have been spectacular and without precedent.

Not until about 1910 were scientific techniques applied to the discovery of petroleum on a rapidly expanding front with the support of the petroleum industry as a whole. We are still in that era of far-flung dynamic operations and the rapid development of new arms in explorations. Since 1920 many new prospecting techniques have been introduced in rapid succession by geology, geophysics, and geochemistry. Applied geology contributed three new techniques; geophysics no less than six techniques, and geochemistry at least two approaches to petroleum prospecting. None of these is an esoteric technique. Basically all contribute pertinent data, which if they are to have commercial value, must be coördinated and directed to one common end—the discovery of petroleum.

The broad sciences of geology, geophysics, and geochemistry, from which have sprung all arms in scientific petroleum prospecting, are, in my opinion, permanently established in organized prospecting. There are many fields in each of these three sciences, not all of which is it reasonable to suppose, have been discovered. Neither should one presume that all possible techniques in any one field of a science have now been conceived, developed, and applied to petroleum prospecting. Most that is known to-day directly concerning occurrences of petroleum sprung from geology. Geochemistry, to which I allot soil-gas analyses, may well make the important genetic contributions of the future.

We have then a very broad base from which to conduct the operations of petroleum prospecting. Some, bewildered by the numerous arms in exploration and their respective rôles and scopes, may contend that this base is a polyglot structure incapable of coördination for consolidated approaches on prospecting. Others may hold, often with justification, that all these arms refute their yesterdays because they first set forth with exhilarating credos of infallibility now disproved. Growing pains do not determine destiny or utility. If there is confusion, it arises not only out of the number, and mobility of the techniques, but also out of an unwillingness of man to understand that all techniques are limited in their respective scopes of commercial application. Above all the branch of prospecting must be contemplated or surveyed in its entirety and as a whole.

All our techniques are motivated by human beings concerned, secondarily at least, with self-preservation, expansion of their domain, and their rank of importance in the industry. I concede that in the capitalistic system altruism is not paramount to survival, growth, or rank. In the long term the accountant's concept of worth prevails. Time is the great leveler of inequalities and distinctions.

Once a broad science breaks into highly specialized fields, and these into

many techniques, many camps with their respective camp-followers come into being. Each has its credo and its opinion of its importance. Each fears ultimate submergence, inferior rank, and even liquidation, certainly when the technique has peaked. Out of optimistic concepts of infallibility in the heyday of wide dynamic acceptance of a technique, and equally the despondent periods of static or sub-marginal use, arise most problems in coöperation between the arms in prospecting.

Paramount in our national economy is the production and maintenance of natural resources vital to its welfare. Irrespective of the economy a technique which fails to prove its commercial value is ultimately discarded—all the King's men and all the King's horses notwithstanding. Business, not science, makes this final decision. We may as well frankly recognize this. We may as well frankly recognize and admit that human nature dominates every arm or technique in petroleum prospecting. And, that there are certain social-economic axioms that can not long be arbitrarily set aside.

Some believe these situations can be met by policies of coördination—put into action by coördinators. Coördination alone will not achieve the end desired—we have seen that tried here and there. Coördination, with coöperation, will solve many problems. We can have only one *esprit de corps*. The final solution lies, perhaps, in consolidation of all arms under a corps commander. That commander must be competent and trained for his duties. His will be a training and a philosophy similar in all respects to the training of the early statesmen, who by fair or ruthless means, raised little England to Empire heights. They will, I assure you, not be men with the manufacturers' outlooks and concepts. If this is the road we shall eventually take, it need not call for the submergence, or loss of identity of any arm or technique in prospecting.

A RETURN TO DYNAMIC PETROLEUM PROSPECTING[1]

HENRY A. LEY[2]
San Antonio, Texas

Here near the original western boundaries of a new nation formed by a treaty signed at Paris in 1783, and within "The Territory of the United States Northwest of the Ohio" it seems appropriate to discuss dynamic petroleum prospecting, especially in view of events which have taken place here in the past 5 years.

Northwest Territory was a New England promotion which acquired from the Federal Congress in 1789 about 5 million acres of land. One million and a half acres of the grant were set aside for the Ohio Company, and the remainder for the private speculation and personal profits of the promoters. Here was a vast empire of virgin country into which poured a stream of pioneers. Motivating this arena for new land enterprise were dynamic men. But before the territory could settle down into static ways the land acquisitions of Jefferson and Jackson drew dynamic men westward to the Pacific.

[1] Presidential talk before the Illinois Geological Society at Mattoon, Illinois, October 26, 1939.

[2] President of the Association.

Later very realistic economic forces established a new means of growth—a new form of business enterprise. Again dynamic forces and policies entered the arena, this time to carry forward corporate industrial enterprises rather than land. In this era the petroleum industry rooted itself.

Petroleum prospecting began in Illinois in 1868, in Indiana in 1884, in Ohio in 1860, and in Kentucky in 1860. By 1914 the high tide of dynamic petroleum exploration in this territory began to ebb. Its supporters moved westward into precisely the same territories of Jefferson and Jackson as had the earlier land pioneers.

Once the high tide of dynamic enterprise passes the enterprise falls away to static conditions. Soon thereafter it declines further into low states of marginal and sub-marginal activities. This is true of all man's activities. Only rarely are there periods of long-sustained dynamic action and subsequent periods of spectacular revival.

You may ask, "Precisely what is meant by dynamic prospecting?" Dynamic prospecting is rapid, widespread, active wildcatting arising from the discovery of significant new oil fields. It is usually accompanied by equally rapid, widespread active acquisition of leaseholds. It is that impetus most responsible for the discovery and creation of petroleum reserves on a national scale of importance. Static prospecting, in contrast, is a state of matter-of-course routine wildcatting accompanied by little or no new land acquisition. It also contributes to our national reserves of petroleum, but at a much slower rate and even at an insufficient rate if long continued.

Petroleum prospecting is as much concerned with the causes and motives underlying the return of dynamic prospecting to an abandoned or submarginal territory as it is in the inception of prospecting in virgin territories. Inasmuch as we must eventually re-examine all our marginal and sub-marginal territories these causes and motives are critical. When phenomenal results can be achieved in territories of this type, as has happened in the past 5 years here in Illinois—more precisely within the past 2 years—we can not be indifferent to the situation.

Your current president, dissatisfied in 1932 with the then state of petroleum geology in this territory, made the following remarks in "Lima-Indiana District, Indiana and Ohio."[3]

> Lima-Indiana district affords unusual opportunities for original structural and stratigraphic studies, local and regional. And until such are made, knowledge is restricted to the factual data, and they are the occurrences (the oil and gas fields) themselves, and the areal surface geology of the territory.

The entry of dynamic petroleum prospecting into virgin territory, historically speaking, appears to rest on a psychology of new worlds to conquer, tinged with the lure of the great unknown, and esoteric philosophies. Only a few men, in high or low places, qualify here. If these empire builders are successful the meek audience follows in a wild and mad rush. Capitalistic society is dynamic so long as there are profits or hopes for profits, but it quickly passes into static discomfort once profits are curtailed. In any one industry there are at all times both dynamic and static operations and operators, some prosperous and others marginal.

There are a number of causes, motives, and conditions leading to ex-

[3] *Geology of Natural Gas* (Amer. Assoc. Petrol. Geol., 1935), pp. 843–52.

tremely low levels of prospecting or its discontinuance in a territory. These, I believe, fall into two major divisions, namely, economic and psychologic. The first arises out of the profits situation, the availability of capital funds at the time, and/or convictions that the utility of prospecting techniques is ended. The second, often most important, is largely a matter of the state of knowledge and utilization of intelligence at the time. Probably that urge which causes boys to rush to fires and men to seek greener pastures is an aspect of the psychologic phenomenon.

Purely economic causes leading to declining activity might bear examination, but they are usually well grounded. States of knowledge and utilization of intelligence at any given time, and particularly at the time that prospecting capital is withdrawing from a territory, always deserve comprehensive analyses and surveys. These rather than ephemeral opinions or measures of economic expediency should determine the course of prospecting. There is a stoic proverb that men are tormented by the opinions they have of things, rather than the things themselves.

In this territory it may be said that the state of geologic knowledge had not yet risen to present-day levels and that the value of geology in prospecting was not widely accepted when dynamic prospecting was abandoned. It is true that most current-day prospecting techniques had not yet been conceived. It may be argued that there were truly greener pastures elsewhere. True. But, what of the 20 subsequent years that the territory lay dormant? I should not charge capital with immovable aloofness, even though I know that certain well placed advisers viewed this territory as the site of misguided marginal operations even as late as July, 1938. Rather, I would believe that dormancy resulted from inadequate utilization of intelligence.

We shall never know how many men may have advocated and urged a return of dynamic exploration to this territory. There were some, else prospecting would not have returned. I believe there would have been more, if we did not have within the petroleum industry itself a situation seriously curbing creative geologic thought and progress. I refer to those mechanical duties, properly a function of the production and not the prospecting department, which are forced upon geological departments. The approaches to and the arts of petroleum prospecting and production are not synonymous.

A return to dynamic petroleum prospecting springs primarily, I think, from creative thought. The introduction and use of a new prospecting technique is sometimes responsible. But, here again, creative thought is or should be responsible for the territory to which the technique is assigned. Creative thought demands that cherished beliefs and prejudices, and all plausible excuses by which we seek to defend long-established opinions and preconceptions must be set aside. Possibly curiosity rather than creative thought is the motivating impulse. Perhaps it is the spirit of the primitive hunt. All of us, I believe, will concede that there has been an almost magical transformation here in Illinois. It began with a flame of geologic thought, free from prejudices. That thought then developed in a stimulating environment, not promiscuously or in haste, but with slow contemplation and undoubtedly with much reflection. It was then "put over," so to speak, with objective ends in view—the discovery of new oil fields. All possible prospecting techniques were brought to bear on the solution of structural problems. The results are evident to-day.

The case for dynamic prospecting does not rise or fall on the final substantiation of all the premises employed to bring it to life. What does it matter if the oil is found in rocks of Mississippian age instead of in predicated reservoirs of Devonian age, if the result is a commercial oil field? The objective end was the discovery of an oil field. One can, on drilling, substantiate every predicated premise and not discover oil. I suspect that many now stand bewildered before the major monuments to dynamic prospecting in this territory. How many more of these territories are there, and which are they?

One can not be too emphatic that dynamic prospecting is not responsible for current ills of the petroleum industry, real or imaginary. It is well to point this out. The end objective of prospecting is the discovery of new oil fields. Prospecting, in no manner, is concerned with development, exploitation, and vicious concepts and practices that lead to price and production chaos. If unsound post-discovery situations are permitted or encouraged to arise, those situations should in no manner determine the course or magnitude of prospecting. Only the magnitude of proved reserves, and the rate at which they are most efficiently produced, should determine the volume of prospecting. An industry, concerned with the welfare of our national economy, recognizes these criteria, and does not confuse or improperly allocate the sources and issues basicly responsible for price and production chaos. Legislators, to-day, may well consider the wide gulf separating prospecting from production and their respective economic objectives and consequences. Prospecting is discovery; production is mining.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 23, NO. 11 (NOVEMBER, 1939), PP. 1747-1750

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

The International Petroleum Exposition will be held at Tulsa, Oklahoma, May 18–25, 1940.

Clifton M. Keeler has charge of the exploration and production work for Ray Stephens, Inc., 1716 First National Bank Building, Oklahoma City, Oklahoma.

W. B. McCarter, salt-dome specialist and appraiser of oil lands, has moved to Houston, Texas, from Lafayette, Louisiana, where he was formerly regional geologist for southern Louisiana and the eastern half of the Gulf Coastal Plain for the Tide Water Associated Oil Company. He may be addressed at 1415 Sul Ross or 2522 Hazard, Houston, Texas.

The Houston Geological Society has elected new officers: president, Wallace C. Thompson, General Crude Oil Company; vice-president, Carleton D. Speed, Jr., Speed Oil Company; secretary, Olin G. Bell, Humble Oil and Refining Company; treasurer, A. P. Allison, Sun Oil Company. An advisory committee is composed of Roy L. Beckelhymer, Union Producing Company; R. J. Metcalf, Ohio Oil Company; and F. W. Rolshausen, Humble Oil and Refining Company.

Robert L. Marston, formerly Mid-Continent regional manager for the Sperry-Sun Well Surveying Company at Houston, is district superintendent for the Sun Oil Company at McAllen, Texas.

H. I. Tschopp has left Guatemala and is with the Shell Oil Company of Ecuador Ltd., Apartado 340, Quito, Ecuador.

René Pomeyrol has a new address: Petroleum Concessions (Syria and Lebanon) Ltd., Deir-ez-Zor, Syria.

Thomas F. Stipp, of the United States Geological Survey, has been transferred from Casper, Wyoming, to Taft, California.

G. H. Crowl, recently with the Shell Oil Company, Inc., at Vincennes, Indiana, is now an instructor in geology at Rutgers University, New Brunswick, New Jersey.

Jack M. Barton, recently with the Magnolia Petroleum Company at Oklahoma City, is engaged in post-graduate work at Yale University. His address is Peabody Museum, Yale University, New Haven, Connecticut.

L. R. Laudon, of the University of Tulsa geological faculty, spoke on the subject, "Geology of Southwestern United States," before the Tulsa Geological Society, October 2.

R. I. Dickey, recently with the Stanolind Oil and Gas Company, is now district geologist for the Forest Development Company at Midland, Texas.

S. A. Lynch, head of the department of geology, North Texas Agricultural College, has taken a year leave of absence to study geology and petroleum engineering at the University of Texas.

LESLIE BOWLING, formerly with the Tide Water Associated Oil Company, is now with the Union Oil Company of California, 903 Kirby Building, Houston, Texas.

C. L. MOHR has changed his address in Fort Worth, Texas, to 4301 Locke Avenue.

FRITZ VON ESTORFF is in the producing department of the Socony-Vacuum Oil Company, Inc., 26 Broadway, New York City.

HENRY ROGATZ, consulting geologist of Amarillo, Texas, spoke before the Panhandle Geological Society, Amarillo, September 28, on "The Geology of the Texas Panhandle."

C. R. MCKNIGHT, geologist with the Arkansas Fuel Oil Company, and H. W. BELL, engineer for the Rodessa Operators Committee, are teaching in the Centenary College night school, Shreveport, Louisiana.

SILAS C. STATHERS, retired chief geologist of the Standard Oil Company of Louisiana of Shreveport, now at his home in Buckhannon, West Virginia, has recovered from his serious illness and is again engaged in professional and civic activities.

GEORGE A. KROENLEIN has resigned as president of the Midland Exploration Company, Effingham, Illinois, and is now located at 710 West Louisiana, Midland, Texas.

CLAUDE M. LANGTON is consultant geologist for the Lane-Wells Company, acting in the capacity of research geologist with the company's "Electrolog" well survey in the Corpus Christi, San Antonio, and Laredo areas. His address is 1700 Second Street, Corpus Christi, Texas.

JACK M. COPASS, of the Amerada Petroleum Corporation, geological staff, has moved from Shawnee, Oklahoma, to Wichita, Kansas.

ROBERT L. CASSINGHAM has been transferred from Wichita, Kansas, to Shawnee, Oklahoma, in the service of the Amerada Petroleum Corporation.

FRANK BUTTRAM, Oklahoma City, has been elected president of the Independent Petroleum Association of America, succeeding Charles F. Roeser of Fort Worth, Texas.

COLEMAN B. RENICK, of the Phillips Drilling Company, has been chosen to lead the South Texas Geological Society group study of the subject, "General Principles of Deposition and Sedimentation." Thirty members in San Antonio and eighteen members in Corpus Christi have indicated an interest in this study. Meetings will be held every Monday at 8:00 P.M. in the San Antonio Petroleum Club rooms and all interested are invited to join the group and attend the meetings.

T. E. WEIRICH, research geologist with the Phillips Petroleum Company, Bartlesville, Oklahoma, talked before the Tulsa Geological Society, October 16, on the subject, "Comparative Geology of the Cincinnati Uplift."

CARTER VICTOR DORRELL discussed "Subsurface Studies in Eastern Colorado," before the Rocky Mountain Association of Petroleum Geologists, Denver, Colorado, October 16.

LEIMO I. PARHIALA has resigned from the Lago Petroleum Corporation to do graduate work in geology at Yale University.

CHARLES F. BOWEN has moved from Salt Lake City, Utah, to 124 Kerr Apartments, Waikiki, Honolulu, Hawaii.

HAROLD O. SMEDLEY is district geologist for the Skelly Oil Company at Wichita, Kansas, succeeding HOWARD S. BRYANT, recently moved to Tulsa.

R. J. GONZALEZ, of the Humble Oil and Refining Company, discussed "Economic and Statistical Aspects of the Petroleum Industry," before the Houston Geological Society, October 12.

R. B. RUTLEDGE is division geologist for Oklahoma and southern states for the Skelly Oil Company, at Tulsa. He is also in charge of geophysical work.

HOWARD S. BRYANT has moved from the position of district geologist for the Skelly Oil Company at Wichita, Kansas, to become division geologist at Tulsa, Oklahoma, for the area of Kansas, Missouri, Illinois, Indiana, and eastern Colorado.

WALTER B. JONES, State geologist of Alabama, has been appointed director of the newly established State Department of Conservation.

MARVIN LEE, consulting geologist of Wichita, Kansas, has returned to his office after more than a year of work and residence in the Forest City basin in northern Missouri.

The Abilene Geological Society, Abilene, Texas, has elected new officers as follows: president, CARL S. SHOULTS; vice-president, K. N. NOWELS; secretary-treasurer, H. C. DANIELS.

URBAN B. HUGHES, consulting geologist, has opened an office in Jackson, Mississippi.

New officers of the Shreveport Geological Society are: president, E. FLOYD MILLER, Oliphant Oil Corporation; vice-president, JAMES D. AIMER, Arkansas Natural Gas Corporation; secretary-treasurer, WELDON E. CARTWRIGHT, Tide-Water Associated Oil Company; historian, ANNA MINKOFSKY, Shell Oil Company, Inc.

J. M. BUGBEE, of the Baroid Sales Department, National Lead Company, Houston, Texas, discussed "New Mud Analysis Logging," before the Shreveport Geological Society, at the first fall meeting at Shreveport, Louisiana, October 6.

H. W. STRALEY, III, formerly of Chapel Hill, North Carolina, has been appointed associate professor and executive officer of the department of geology at Baylor University, Waco, Texas. He assumed his new duties on the first of September and may be addressed at P.O. Box 363, Waco, Texas.

FRANK A. MELTON, professor of stratigraphy in the School of Geology at the University of Oklahoma, Norman, addressed the combined groups of the West Geological Society, the Fort Worth Geological Society, and the Texas Academy of Science on "Some Phases of the Application of Aerial Photography to Geology," following the dinner at the University Commons, University of Texas, at Austin, November 11.

JOHN C. HAFF, petrologist, has been engaged by the Colorado School of Mines as an assistant professor of geology for the ensuing year. In 1938–39 he was on the staff of Wichita University, Wichita, Kansas.

President Henry A. Ley, of San Antonio, Texas, recently completed the following itinerary, talking before local geological groups in the interest of the Association.

October 21, South Texas Section, American Association of Petroleum Geologists, Brownsville, Texas: "Mutual Responsibilities"
October 23, Dallas Geological Society, Dallas, Texas: "Coöperation between Arms in Prospecting"
October 25, Tulsa Geological Society, Tulsa, Oklahoma: "Mutual Responsibilities"
October 26, Illinois Geological Society, Mattoon, Illinois: "A Return to Dynamic Prospecting"
October 27, Geology Majors, University of Illinois, Champaign, Illinois: "The Employment Outlook"
November 3, Appalachian Geological Society, Charleston, West Virginia
November 6, Geology Majors, University of Kansas, Lawrence, Kansas: "Fields in Geology"
November 7, Kansas Geological Society, Wichita, Kansas
November 9, Pacific Section, American Association of Petroleum Geologists, Los Angeles, California: "Prospecting in Our National Economy"

The fifty-second annual meeting of the Geological Society of America will be held at Minneapolis, Minnesota, December 28–30. Joint meetings will be held by the Society of Economic Geologists, the Mineralogical Society, and the Paleontological Society.

The annual meeting of the American Institute of Mining and Metallurgical Engineers will be held in New York City, February 12–15, 1940.

The twenty-fifth annual meeting of the American Association of Petroleum Geologists will be held in Chicago, April 10–12, 1940.

PROFESSIONAL DIRECTORY

Space for Professional Cards Is Reserved for Members of the Association. For Rates Apply to A.A.P.G. Headquarters, Box 979, Tulsa, Oklahoma

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SAN FRANCISCO, CALIFORNIA

RICHARD R. CRANDALL
Consulting Geologist
404 Haas Building
LOS ANGELES, CALIFORNIA

J. E. EATON
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PAUL P. GOUDKOFF
Geologist
Geologic Correlation by Foraminifera and Mineral Grains
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ROCKY MOUNTAIN ASSOCIATION OF PETROLEUM GEOLOGISTS

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985 Gilbert Street, Boulder
1st Vice-President - - - David B. Miller
1336 Gaylord Street
2nd Vice-President - - - Harold N. Hickey
810 U. S. National Bank Building
Secretary-Treasurer - - - - - - Ninetta Davis
224 U. S. Customs Building

Dinner meetings, first and third Mondays of each month, 6:15 P.M., Auditorium Hotel.

ILLINOIS

ILLINOIS GEOLOGICAL SOCIETY

President - - - - - - - Verner Jones
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Vice-President - - - - Melville W. Fuller
Carter Oil Company, Mattoon

Secretary-Treasurer - - Elmer W. Ellsworth
W. C. McBride, Inc., Centralia

Meetings will be announced.

KANSAS

KANSAS GEOLOGICAL SOCIETY

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Vice-President - - - - Thomas H. Allan
Consulting Geologist
Secretary-Treasurer - - - - E. Gail Carpenter
Consulting Geologist
Manager of Well Log Bureau - Harvel E. White

Regular Meetings: 7:30 P.M., Allis Hotel, first Tuesday of each month. Visitors cordially welcomed.

The Society sponsors the Kansas Well Log Bureau which is located at 412 Union National Bank Building.

LOUISIANA

THE SHREVEPORT GEOLOGICAL SOCIETY

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Vice-President - - - - - - James D. Aimer
Arkansas Natural Gas Corporation
Secretary-Treasurer - - - Weldon E. Cartwright
Tide Water Associated Oil Company

Meets the first Friday of every month, 7:30 P.M., Civil Courts Room, Caddo Parish Court House. Special dinner meetings by announcement.

SOUTH LOUISIANA GEOLOGICAL SOCIETY

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Vice-President - - - - - H. E. McGlasson
Stanolind Oil and Gas Company
Secretary - - - - - - - G. O. Grigsby
Stanolind Oil and Gas Company
Treasurer - - - - - - - Baker Hoskins
Shell Oil Company, Inc.

Meetings: Luncheon 1st Wednesday at Noon (12:00) and business meeting third Tuesday of each month at 7.00 P.M. at the Majestic Hotel. Visiting geologists are welcome.

MICHIGAN

MICHIGAN GEOLOGICAL SOCIETY

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The Pure Oil Company, Saginaw

Vice-President - - - - - - Jed B. Maebius
Gulf Oil Corporation, Saginaw

Secretary-Treasurer - - - - R. P. Grant
Michigan Geological Survey, Lansing

Business Manager - - - - Helen Martin
Michigan Geological Survey

Meetings: Monthly dinner meetings rotating between Saginaw, Mt. Pleasant, and Lansing. Informal dress.

OKLAHOMA

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Vice-President - - - - - - - - - J. P. Gill
Sinclair Prairie Oil Company

Secretary-Treasurer - - - W. Morris Guthrey
The Texas Company

Meetings: First Tuesday of each month, from October to May, inclusive, at 7:30 P.M., Dornick Hills Country Club.

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OKLAHOMA CITY, OKLAHOMA

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Oklahoma Corporation Commission

Vice-President - - - - Albert S. Clinkscales
Consulting Geologist, Colcord Building

Secretary-Treasurer - - - - - - R. Hancock
Magnolia Petroleum Corporation

Meetings, Ninth Floor, Commerce Exchange Building: Technical Program, second Monday, each month, 8:00 P.M.; Luncheons, every Monday, 12:15 P.M.

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Vice-President - - - - - J. Lawrence Muir
Amerada Petroleum Corporation

Secretary-Treasurer - - - - Tom L. Girdler, Jr.
Sinclair Prairie Oil Company

Meets the fourth Monday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

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Secretary-Treasurer - - - - Wendell S. Johns
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Editor - - - - - - - - - A. N. Murray
University of Tulsa

Associate Editor - - - - Maurice R. Teis
Homestake Companies

Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., University of Tulsa, Kendall Hall Auditorium. Luncheons: Every Thursday, Michaelis Cafeteria, 507 South Boulder Avenue.

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Vice-President - - - - - - W. W. Clawson
Magnolia Petroleum Company

Secretary-Treasurer - - - Henry J. Morgan, Jr.
Atlantic Refining Company

Executive Committee - - - Eugene McDermott

Meetings: Regular luncheons, first Monday of each month, 12:15 noon, Petroleum Club. Special night meetings by announcement.

EAST TEXAS GEOLOGICAL SOCIETY
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Shell Oil Company, Inc.

Vice-President - - - - - - E. M. Rice
Pure Oil Company

Secretary-Treasurer - - - - - C. I. Alexander
Magnolia Petroleum Company

Meetings: Monthly and by call
Luncheons: Every Monday at 12:00 noon, Blackstone Hotel.

TEXAS

FORT WORTH GEOLOGICAL SOCIETY
FORT WORTH, TEXAS

President - - - - - - - J. Earle Brown
Consulting Geologist, Trinity Life Building

Vice-President - - - - - J. H. Markley
The Texas Company

Secretary-Treasurer - - - - Vernon Lipscomb
The Pure Oil Company

Meetings: Luncheon at noon, Worth Hotel, every Monday. Special meetings called by executive committee. Visiting geologists are welcome to all meetings.

HOUSTON GEOLOGICAL SOCIETY
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Secretary - - - - - - - - - - - Olin G. Bell
Humble Oil and Refining Company

Treasurer - - - - - - - - - - A. P. Allison
Sun Oil Company

Regular meetings held every Thursday at noon (12 o'clock) above Kelly's Restaurant, 910 Texas Avenue. For any particulars pertaining to the meetings write of call the secretary.

NORTH TEXAS GEOLOGICAL SOCIETY
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Secretary-Treasurer - - - - - - R. E. McFail
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Luncheons and evening programs will be announced.

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Secretary-Treasurer - - - - Robert N. Kolm
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Executive Committee - - - - - E. L. Porch

Meetings: Third Friday of each month at 8 P.M. at the Petroleum Club. Luncheons every Monday noon at Petroleum Club, Alamo National Building, San Antonio, and at Plaza Hotel, Corpus Christi.

SOUTHWESTERN GEOLOGICAL SOCIETY
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Univ. Texas, Dept. of Geology

Vice-President - - - - - - Leo Hendricks
Bureau of Economic Geology

Secretary-Treasurer - - - - - - W. C. Ikins
Univ. Texas, Dept. of Geology

Meetings: Every third Friday at 8:00 P.M. at the University of Texas, Geology Building 14.

WEST TEXAS GEOLOGICAL SOCIETY
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University Lands

Vice-President - - - - - - W. C. Fritz
Skelly Oil Company

Secretary-Treasurer - - - - J. E. Simmons
Continental Oil Company

Meetings will be announced

WEST VIRGINIA

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Owens, Libbey-Owens Gas Department

Vice-President - - - - - - J. R. Lockett
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Columbus, Ohio

Secretary-Treasurer - - - Charles Brewer, Jr.
Godfrey L. Cabot, Inc., Box 348

Meetings: Second Monday, each month, at 6:30 P.M., Kanawha Hotel.

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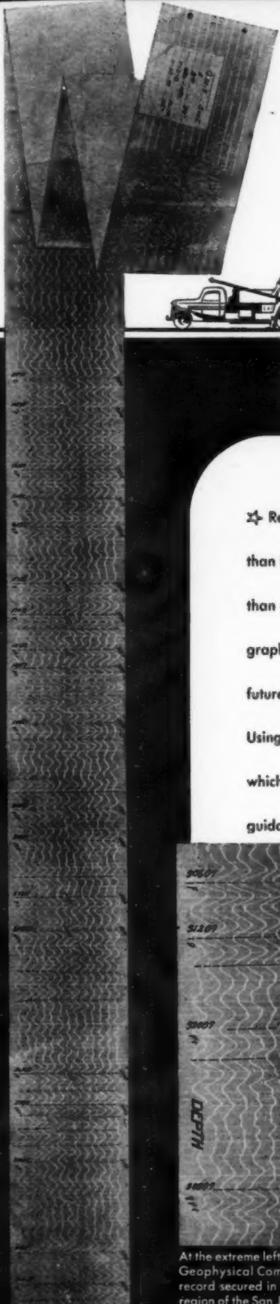

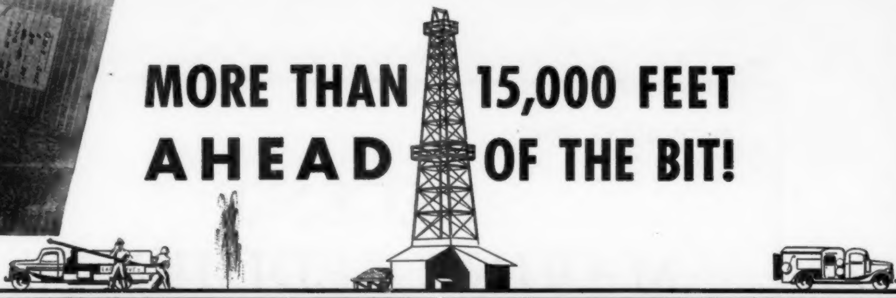


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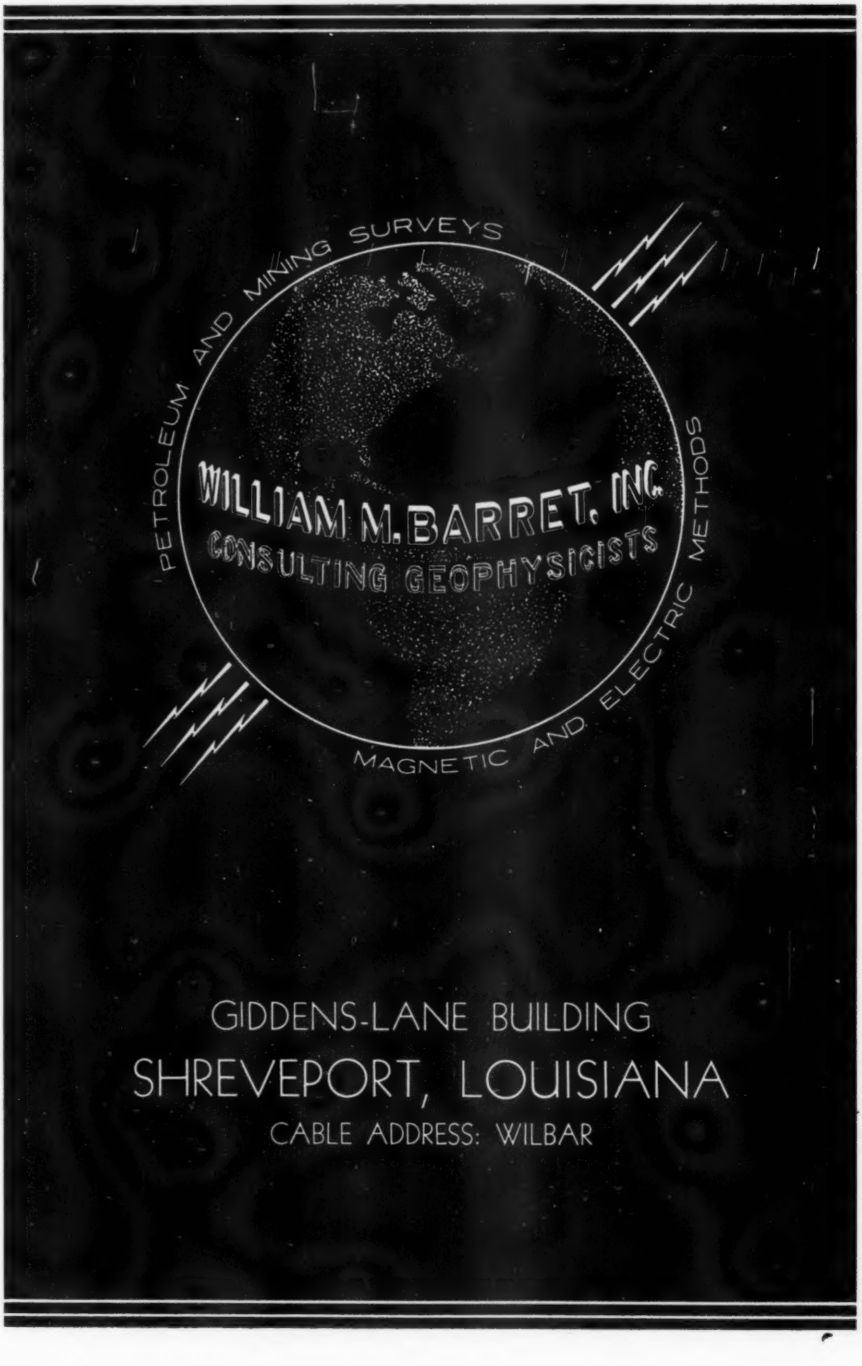
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CORE BIT
In drilling deep wells, there comes a time when a large, unbroken, uncontaminated core must be had. Then is when it pays to send down a Hughes conventional Core Bit . . . and "know" when you come out you will have the kind of core you want.
Hard and soft formation cutter heads
for varying formations.
HUGHES TOOL CO.